The Institution of Gas Engineers

JOURNAL

MARCH 1961
VOLUME 1 NUMBER 3

BALFOUR of LEVEN

offer to the Gas Industry
a complete service covering design and installation
for the most modern types of plant

GAS TREATMENT PLANT

TOWER BOX PURIFIERS
SECTIONAL TOWER PURIFIERS
CONVENTIONAL BOX PURIFIERS
FRODINGHAM PROCESS PURIFIERS
GIAMMARCO PROCESS
DETOXIFICATION
GAS COUNCIL TRACE PURIFICATION PROCESS
CONDENSERS, WASHERS, ETC.

BALFOUR GROUP

ENAMELLED METAL PRODUCTS CORPORATION (1933) LTD.

GEORGE SCOTT & SON (LONDON) LTD.

OTHER GAS PLANT

GAS COUNCIL HIGH PRESSURE PROCESSES
SPIRAL GUIDED GAS HOLDERS
COLUMN GUIDED GAS HOLDERS
SMOKELESS FUEL PLANT
WATER GAS PLANT
SULFAGEN PROCESS
GAS REFORMING PLANT
GENERAL ANCILLARY PLANT

HENRY BALFOUR & CO. LTD., LEVEN, FIFE, SCOTLAND.
London Office: Artillery House, Artillery Row, London, S.W.1.
Telephone: ABBey 3639.

Over 150 years leaders in Scotland's Industry.

The Institution of Gas Engineers

Founded 1863 Royal Charter 1929

Patron: Her Majesty The Queen

President

H. S. CHEETHAM, M.I.Mech.E., M.I.Chem.E.

Vice-Presidents

T. C. BATTERSBY, M.B.E., M.I.Mech.E. A. E. HAFFNER, Ph.D., B.Sc., M.I.Chem.E., A.R.C.S., D.I.C.

Honorary Secretary

G. E. CURRIER, O.B.E., M.I.Mech.E.

Secretary

W. T. K. BRAUNHOLTZ, O.B.E., M.A., Ph.D., F.R.I.C.

Secretary-Designate

A. G. HIGGINS, M.Sc., F.R.I.C.

Assistant Secretary

J. R. DAVIDSON, B.Sc.

Finance Officer

A. W. KING, A.A.C.C.A.

Editor

BEN. MORGAN, M.A.A.

Advertisement Manager

H. P. HOWELL

Librarian

D. P. JOHNSON, B.A., A.L.A.

JOURNAL

Vol. 1, No. 3 March, 1961

CONTENTS

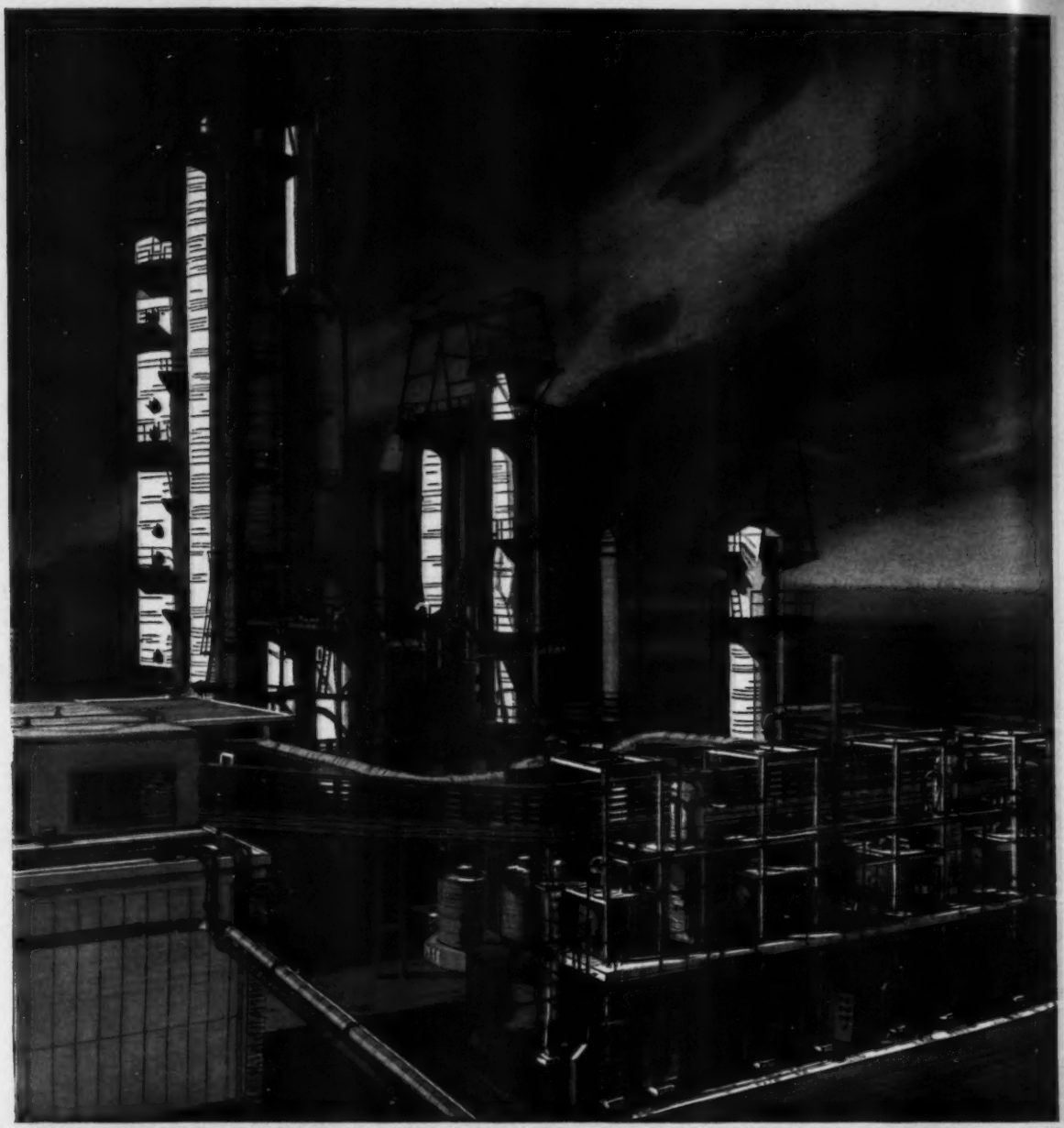
	Page
COMBINED TOWN GAS/FUEL OIL FLAMES FOR HEATING FERROUS METALS By E. A. K. Patrick, B.Sc., F.R.I.C., M.I.Gas E., M.I.Chem.E. (Officer-in-Charge), and N. G. Patel, B.Sc.(Chem. Eng.) (Chemical Engineer), Industrial Laboratory, Watson House, London Research Station, The Gas Council	157
REPORT ON THE GAS COUNCIL SCHOLARSHIPS: 1960	184
IN THIS ISSUE	186
EXPERIENCES WITH BRANCHED-FLUE AND SE-DUCT SYSTEMS FOR VENTING GAS APPLIANCES (Concluded.) By W. J. Bennett, M.Sc. B.Sc.(Eng.), A.M.I.Gas E.; C. H. Purkis, B.A., B.Sc., M.I.Gas E., A.M.I.H.V.E.; J. B. Carne, B.Sc., and T. T. White, B.Sc., A.R.C.S.	187
PROCEEDINGS OF COUNCIL	205
MEMBERSHIP REGISTER	205
BINDING OF JOURNAL	205
CHRISTMAS LECTURE FOR YOUNG PEOPLE ...	206
SHORT COURSE FOR TEACHERS OF GAS TECHNOLOGY	206
JOINT MEETING	207
TRANSLATIONS OF FOREIGN PAPERS	207
INSTITUTION REGISTER	207
PERSONAL NOTES	208
DISTRICT SECTIONS AND AFFILIATED ASSOCIATIONS:	
(*a*) Notes of Meetings	208
(*b*) Abstracts and Discussions of Papers ...	209
NEWS FROM THE GAS INDUSTRY OVERSEAS ...	217
FORTHCOMING MEETINGS:	
(*a*) District Sections	219
(*b*) Junior Gas Associations	219
(*c*) Kindred Bodies	220
LIBRARY ACCESSIONS	221
GENERAL NOTICES	222

The Institution of Gas Engineers as a body is not necessarily responsible for the statements made, nor for the opinions expressed, in the following pages.

Published by The Institution of Gas Engineers, 17, Grosvenor Crescent, London, S.W.1

Subscription Rates: 7s. 6d. per copy, post free; £4 10s. per annum, post free.

Telephone: BELgravia 8266. *Telegrams: Gasophaner, Knights-London.*



An artist's impression of the High Pressure Oil Gasification Plant nearing completion at the Isle of Grain Works of the South Eastern Gas Board

WOODALL-DUCKHAM
CONSTRUCTION COMPANY LTD
Woodall-Duckham House · 63-77 Brompton Road · London · S.W.3
Tel: KENsington 6355 (14 lines) Telegrams: Retortical (Southkens) London
A MEMBER OF THE WOODALL-DUCKHAM GROUP OF COMPANIES

COMBINED TOWN GAS/FUEL OIL FLAMES FOR HEATING FERROUS METALS

By E. A. K. PATRICK, B.Sc., F.R.I.C., M.I.Gas.E., M.I.Chem.E.
(*Officer-in-Charge*)

and

N. G. PATEL, B.Sc.(Chem.Eng.)
(*Chemical Engineer*)
Industrial Laboratory, Watson House, London Research Station, The Gas Council

RESEARCH COMMUNICATION GC67

TABLE OF CONTENTS

		PAGE
I	Summary	158
II	Introduction	153
III	Nomenclature	159
IV	Previous Work	159
	(A) Combined Town Gas/Fuel Oil Flames	159
	(B) Heating of Ferrous Metals	159
V	Description of Plant	160
	(A) Furnace	160
	(B) Burner	161
	(C) Fuel and Air Supplies	162
	(D) " Hammer Test " Apparatus	162
VI	Burner Performance	163
	(A) Self-proportioning	163
	(B) Excess Air	163
	(C) Adventitious Air	164
VII	Programme for Work on Metal Heating	165
	(A) Selection of Steels	165
	(B) Experimental Plan	165
VIII	Procedure	165
	(A) Temperature	165
	(B) Furnace Atmosphere	166
	(C) Preparation of Steel Samples	166
	(D) Scaling Loss	166
	(E) Quantity of Adherent Scale	166
	(F) Analysis of Scale	167
	(G) Decarburization	167

IX Results 167
(A) Accuracy of Experiments 167
(B) Scaling Loss *versus* Time 167
(C) Quantity of Adherent Scale *versus* Time 168
(D) Scaling Loss *versus* Excess Air 169
(E) Quantity of Adherent Scale *versus* Excess Air 172
(F) Examination of Scale 173
(G) Decarburization 174

X Conclusions 177
Acknowledgments 178
Literature References 178

APPENDIX
Calculation of Flue Gas Composition for Combined Town Gas/Fuel Oil Flames 179
Presentation, Discussion and Reply 181

I SUMMARY

Investigations carried out on the application of gas/oil burners to the heating of steel for forging are reported. The effect of types of fuel (i.e., fuel oil, town gas, and various mixtures of fuel oil and town gas) at differing excess air and times of heating on the quantity and adherence of scale formed on mild steel and alloy steels, was studied. Decarburization of steel surfaces has also been considered.

While the work has not produced evidence that the combined flame offers any major advantage in its effect on ferrous metals, it appears that town gas would have a marked advantage over fuel oil if, in the pursuit of thermal efficiency, the level of excess air in forge furnaces were consistently held below 10 per cent. This effect is largely a function of the sulphur content of the fuels.

II INTRODUCTION

The origin of the work described in this Paper can be found in measures taken, during the Second World War, to provide alternative sources of fuel in key factories where town gas was in normal use. This gave rise to burners that could readily be changed from town gas to an oil fuel, the change usually necessitating the exchange of one or more components of the burner. Such burners were generally regarded as a wartime expedient and did not remain in common use in this country after the War. In the United States, however, where natural gas is a cheaper fuel than oil, but where the natural gas supply system at that time was finding difficulty in meeting winter loads, tariffs were in force that encouraged the use of oil as a standby fuel for winter peak periods or for the whole winter. It is a requirement of a standby burner that change of fuel should be easy, and it was, therefore, a natural development to design burners in which no change of components was necessary in order to change the fuel, this being simply effected by operation of the appropriate valves. A further step led to the use of both fuels simultaneously in the one burner. This stage having been reached, it began to be suggested[1, 2, 3] that the combined flame that had been evolved for economic reasons did, in fact, possess intrinsic virtues not possessed by oil or (natural) gas flames independently.

In this country, the next fillip received by this development may be attributed to the Suez crisis. In the intervening years, the use of oil as an industrial fuel had grown considerably and the fear now was of shortage of oil, which required to be insured against by the provision of burners capable also of burning town gas. Interest in this occasioned an article in the technical press[4] in September, 1956, which discussed the potentialities of such burners, and at about this time it became evident that British industry and British burner manufacturers were also interested.

There are some obvious advantages of a burner that can burn alternative fuels, namely, insurance against shortage of either fuel, ability to take advantage of price changes and the use of town gas for ignition and turn-down periods. The high rating of the burners likely to be evolved makes the use of town gas for standby purposes generally unattractive to the Gas Industry, but the other considerations listed above give the prospect of useful additional load. There remain, however, those claims for these burners that are based on special properties of the combined town gas/fuel oil flame, and it was these that appeared to require scientific investigation. If it could be shown that the addition of a small proportion of the relatively high-priced town gas to a heavy oil could produce substantial benefits in the operation of the process, resulting in financial saving or increased productivity, then, since heavy oil is normally used on large units, the potential gas load involved might be considerable. A programme of work was, therefore, initiated to assess the validity of some of the claims made for the combined flame and their relevance to British conditions.

The possibility that the intensity and distribution of the radiant heat output from an oil flame could be usefully modified by burning town gas simultaneously with oil is being investigated for The Gas Council in the Department of Fuel Technology and Chemical Engineering at the University of Sheffield, under the direction of Professor M. W. Thring.

This Paper, after reviewing a not very abundant literature and describing the apparatus used and the test methods that had to be evolved, presents a study of the effect of fuel oil, town gas and combined town gas/fuel oil flames on scale formation and decarburization of three carbon steels and one nickel–chromium–molybdenum steel.

III NOMENCLATURE

The nomenclature given to gas/oil burners by the various burner manufacturers differs. There are two basic types of gas/oil burner available in this country: one in which gas and oil can only be burned separately, and the other in which gas and oil can be burned either separately or simultaneously, i.e., as a combined fuel. A third possible type of burner is one that would operate on combined fuel only. The nomenclature used in this Paper is based on one given in the literature[4], and is as follows:—

Dual-fuel burners, which can burn gas or oil separately, but not together.

Combination gas/oil burners, which allow gas and oil to be burned either separately or simultaneously.

Further classification follows that of conventional oil burners, that is, as pressure jet, blast or rotary, and the usual nomenclature of gas burners.

IV PREVIOUS WORK

(A) Combined Town Gas/Fuel Oil Flame

Little information is available in the literature on the combined town gas/fuel oil flame. Some publications[4, 5] have dealt with the description and nomenclature of gas/oil burners and have discussed the possible advantages of these burners. A number of investigations[3, 6, 7] of the combination of oil with town gas, coke oven gas, or natural gas, are concerned mainly with the rates of heat transfer from the combined flame, in which gas usually represents the major proportion of the fuel. An investigation of the scaling and decarburization of steels heated to forging temperatures by combined oil and coke oven gas flames in which coke oven gas is the main fuel, has been published.[8]

In this country, gas/oil burners are, at present, of simple design in which either an adaptor forming an annular gas port, or a gas ring with a number of circular ports, is fitted around the nozzle of a conventional oil burner. This arrangement has been adopted for the sake of convenience in the production of the burners. The effect of the relative positions of oil, gas and air outlets and the proportions of fuels and air on combined town gas/fuel oil flames need to be investigated in order to obtain a basis for the design of gas/oil burners. Work on combined town gas/fuel oil flames in progress at the University of Sheffield may reveal the optimum conditions for heat transfer from such flames. In Germany, considerable interest has been shown in gas/oil burners.[5]

The advantages that have been suggested for gas/oil burners are summarized below. Some of these are concerned with separate use of the two fuels and are quite obvious, while others, which refer to combined fuels, are generally based on claims made for combination gas/oil burners using natural gas or coke oven gas.

(1) Gas can be used for heating up furnaces from cold and so obviate smoke nuisance experienced with oil burners when fired in cold furnaces.

(2) Gas is a suitable fuel for low rates of heating, and, therefore, the turn-down ratio of oil burners is extended beyond their normal limit.

(3) In the event of breakdown of oil-burning equipment, or shortage of oil, gas can be turned on and production continued.

(4) Where heating rates are critical (e.g., in the heating of heavy forging) both highly radiant oil flames and nearly non-luminous gas flames are available.

(5) Under conditions in which oil will only burn satisfactorily if a large amount of excess air is supplied, a reduction in the excess air required may be obtained by using a combined town gas/fuel oil flame.

(6) The scaling loss and the harmful effects of scaling, decarburization or spot carburization of metal heated by oil may be minimized by heating with town gas/fuel oil flames.

(7) Low-temperature corrosion of metals by products of combustion of oil may be reduced by burning gas in combination with oil, which may increase the $SO_2 : SO_3$ ratio in the products of combustion.

(8) The unburnt fuel from oil flames and the high radiation from the flame are responsible for deterioration of furnace refractories in oil-fired furnaces. The use of combined fuels may result in increased furnace life and also gain in thermal efficiency if it allows the application of insulating firebricks in place of the dense bricks normally employed in the construction of oil-fired furnaces.

(9) The use of gas in combination with oil may improve the combustion of oil, as gas burns at a much faster rate than oil. The characteristics of the oil flames, such as heat release pattern, may be altered to give a better temperature distribution than that obtained in oil-fired furnaces.

(B) Heating of Ferrous Metals

The problems encountered in the heating of ferrous metals are: the economic use of fuel, the attainment of proper temperatures and heating rates, and the prevention of scaling and alterations in the chemical composition of the metals. The majority of furnaces for heating ferrous metals are directly fired and the combustion of fuel is usually carried to completion. The furnace atmosphere comes into contact with the metal at high temperatures.

Scaling and decarburization of the metal has a direct bearing on the cost of production. The scale itself represents a direct financial loss. Heavy expenditures are also incurred in the descaling of the metal and the removal of the decarburized layer. The quality of the scale (i.e., whether it is of the adherent or non-adherent type) is, moreover, often more important than the quantity of scale. Adherent scale increases the cost of descaling, tends to be embedded in the metal during hot working, and is harmful to forge dies. Scales also attack furnace refractories, thereby shortening the life of the furnace.

The fact that manufacturing costs could be decreased by minimizing the scaling of metal and the adherence of scale has long been realized. Various methods of heating are known to counteract scaling, such as the use of indirectly fired furnaces, heating in specially prepared furnace atmospheres,[9] and direct heating in reducing atmospheres produced by incomplete combustion of fuel[10, 11, 12]. These methods are employed for special cases where the increased capital or running costs can be tolerated. Other reasons against the use of these methods of heating are: the low rate of heating in indirectly fired furnaces, difficulties of charging and discharging when using specially prepared furnace atmospheres, and a tendency for the adherence of the scale to increase in reducing atmospheres.[10, 13]

Research on the scaling of metals at elevated temperatures, reported in the literature, is concerned with the mechanism of scale formation, and the effect of time, temperature, composi-

tion of metal, size of workpiece, composition and velocity of furnace gases, on the rates of scaling of metals and the physical and chemical nature of the scale. Reviews of this work have been published.[14, 15] Generally, the experiments were performed using gases such as carbon dioxide, oxygen, nitrogen, sulphur dioxide, steam and carbon monoxide, and hydrocarbon gases, either singly or as combinations of two or more of these gases.[16, 17, 18] Unfortunately, the scaling behaviour of metals in furnace atmospheres cannot be deduced from the experimental results available for simple gases and their mixtures, and, therefore, synthetic atmospheres, made by mixtures of simple gases, to simulate industrial furnace atmospheres have been used.[19, 20, 21] Work has also been carried out using industrial atmospheres produced from different fuels.[8, 10, 13, 22]

The adherence of scale to metals has been investigated qualitatively,[24, 25] but quantitative information and suitable methods of measuring adherence of scale are rarely found. A method[13] in which cold scaled samples were alternately dropped from a given height and weighed for a number of times was employed to determine the adherence of scale formed on steel when heated to heat-treatment temperatures in coal-fired furnace atmospheres.

The changes that accompany scaling of metals in the composition of the metal beneath the scale have also been investigated.[26, 27, 28]

The general conclusions of the work reported in the literature on the scaling of steels may be briefly summarized as follows:—

(1) The scaling of metal is mainly an oxidation process in which the metal reacts with components of the furnace gases, normally oxygen, steam and carbon dioxide. Oxygen is the most reactive of these components. At high temperatures, the oxidizing power of steam and carbon dioxide is appreciable. Steam has been found to be more active than carbon dioxide in forming scale.[16, 17, 18]

(2) The generally accepted mechanism of scaling is that of counter-current diffusion, the metal diffusing outwards and the oxygen inwards through the scale deposit. The rate of scaling, therefore, depends to a large extent on the properties of the scale, such as structure, composition and melting point.[29, 30]

(3) The scale formed on various metals is generally composed of different oxides of iron, and, depending on the conditions under which the scale is formed, three distinct layers may be identified, each differing in its appearance, structure and composition. The uppermost layer is richest in oxygen and consists mainly of ferric oxide, the middle layer of magnetic oxide of iron, and the layer adjacent to the metal of ferrous oxide.[29, 30]

(4) It has been shown mathematically that the relationship of scale formation with time is parabolic, so that the amount of scale increases and the rate of scaling decreases with time of heating. This relationship is valid for initial stages of oxidation when the oxides formed are dense and have a uniform resistance to diffusion processes. Erratic experimental results have been obtained as the thickness of scale increases, because of the appearance of fissures and " blisters ".[31]

(5) Increase in temperature generally increases the extent of scaling, and the scaling of mild steel becomes considerable above 800°C. Within a certain limited range of temperatures, a decrease in the scaling with increase in temperature has been observed for certain atmospheres.[17]

(6) Above a certain critical value, the velocity of the gas stream has a negligible effect on the scaling of metals. This critical value is of the order of 5 ft/min., but depends on the nature of the scaling gases and the temperature.[17]

(7) Scaling loss is independent of the shape of the workpiece and is generally proportional to the area of the metal exposed to the furnace gases.

(8) In the presence of reducing gases, such as carbon monoxide, hydrogen and hydrocarbons from incomplete combustion of fuel, the scaling of metals is less severe than in oxidizing gases only.[10, 11, 12]

(9) The effect of sulphur dioxide in the furnace atmosphere from sulphur-bearing fuel is to increase scaling, and the scale formed in such atmospheres is composed of sulphides and oxides of iron. Scaling in atmospheres containing sulphur dioxide is particularly severe at high temperatures and when the concentration of free oxygen is low. Under these conditions, iron oxide and sulphide form an iron oxide/sulphide eutectic at the scale-metal interface, and, because of the low melting-point of this complex (930°C), a molten layer of scale is formed that has a low resistance to diffusion of iron and oxygen, and, therefore, causes a rapid increase in scale formation.[20, 21, 22]

(10) The scale formed in reducing or low-excess air atmospheres is generally more adherent than that formed in high-excess air atmospheres.[10, 13] A tight, dense scale tends to be more adherent than loose, porous scale. The adherence of scale is considered to be due to the penetration of the scale into the metal along the grain boundaries.[24, 25] The eutectic type of scale referred to above is responsible for strongly adherent scale because of the intense intercrystalline penetration of the scale into the metal.[21]

(11) The changes in the composition of the metal surface beneath the scale occur by diffusion of metal or carbon outwards, or penetration of scale inwards. The final results will depend on the relative rates of scaling and changes that occur in the metal underlying the scale during its growth. The most important effect is decarburization, which is found normally to decrease in the presence of scale.[26, 27, 28]

(12) Scaling behaviour of alloy steels cannot be generalized, as each alloying element and the proportions of these elements will affect scaling characteristics. Some elements, such as chromium, aluminium and silicon form a protective oxide layer on the surface and reduce scaling. The extent to which various alloys are protected by this oxide layer will depend on its stability, which is governed by the temperature and the composition of the furnace atmosphere.[21]

V DESCRIPTION OF PLANT

(A) FURNACE

The furnace (Figure 1) consisted of a frame of mild steel with brickwork of insulating refractory. A refractory coating was applied to the inside surfaces of the furnace to protect the brickwork and to reduce the leakage of air through the furnace walls. A number of observation ports were provided in the

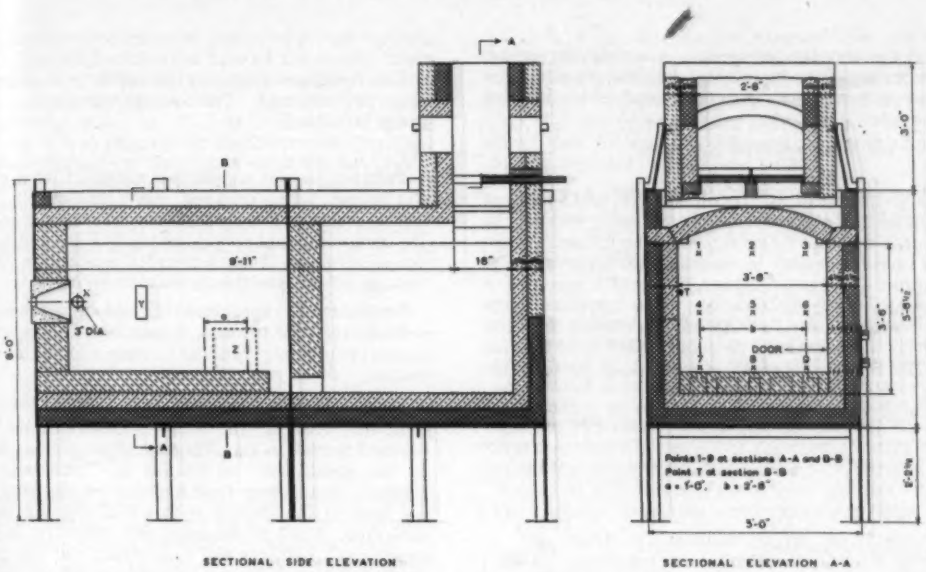


FIGURE 1.—*Experimental Furnace.*

side walls of the furnace, but these were closed for the experiments on scaling, except for the one at the burner end, which was fitted with a 3 in. diameter metal tube containing a flap valve. This port formed the secondary air inlet to the furnace.

Three arrangements of the furnace were used, namely, (*a*) full-size 10 ft × 3 ft 6 in. × 3 ft 6 in. with top flue outlet; (*b*) reduced to 5 ft × 2 ft × 2 ft with top flue outlet; and (*c*) enlarged to 5 ft × 3 ft 6 in. × 3 ft with bottom flue outlet as shown in Figure 1. At this stage, the hearth level was raised slightly above the bottom flue outlet, to give a more uniform furnace atmosphere for the investigation of the scaling of metal. An opening with a door was provided at the side of the furnace at the flue outlet end. Figure 1 shows also sampling-points for furnace gases, positions of adventitious air inlets, and the point at which the furnace temperature was measured.

(E) BURNER

A proprietary burner (Figure 2) was used; for the purposes of description, it may be regarded as composed of two parts, oil- and gas-burner units.

The oil-burner unit is of the two-stage, low-pressure air blast atomizing type and has a maximum capacity of about 4 gal/hr of fuel oil, which is approximately equivalent to 730,000 B.t.u./hr. The turn-down ratio is of the order of 5 : 1. The output of the unit is controlled by the operating lever (A) connected by a linkage (D) to the oil valve stem (B) and the air valve stem (C). The interconnexion of the oil and air valves by this system makes the unit self-proportioning in that an approximately constant oil : air ratio can be maintained when the output is altered by the movement of the operating lever. The oil and air rates can be adjusted independently by simply loosening the link (D) between the stems of the oil and air valves. The experiments required accurate control of the furnace atmosphere, and, therefore, a vernier mechanism was attached to the oil valve stem, which enabled fine adjustments to be made.

The gas stream makes use of the air emerging from the oil burner. The operating lever (A) is connected by an adjustable linkage to the gas valve (E) so that, after adjustment, the gas : air ratio is self-proportioning upon movement of the operating lever (A). A pointer (F) moves an obturator, which, by restricting the gasway, controls the gas : air ratio. Thus, overall adjustment is by setting oil : air and gas : air ratios; thereafter, the burner is controlled simply by the use of the lever (A). The maximum output of the burner on town gas is also about 730,000 B.t.u./hr.

The combination gas/oil burner so formed can burn either gas or oil separately, or simultaneously using any proportion of each fuel. It should be noted that the combustion air is supplied through an annular outlet positioned between the

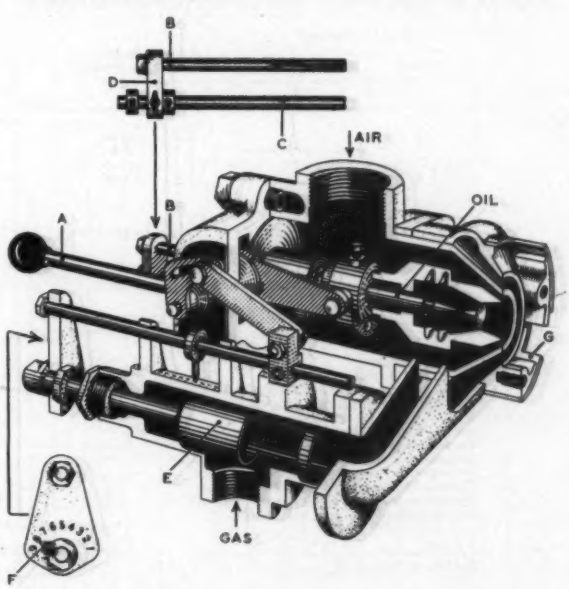


FIGURE 2.—*Schieldrop Combination Gas/Oil Burner.*

oil orifice and the annular gas orifice. A simple air register (G) allows secondary air to be induced into the furnace. The burner was set in a refractory quarl provided with a lighting port.

(C) Fuel and Air Supplies

Fuel Oil

The ancillary equipment for the preparation and supply of oil was assembled in a conventional ring main system. In order to obtain a constant composition of the furnace atmosphere, it was found necessary to maintain the temperature of the oil to within a closer limit than the ±10°F given by a proprietary heater, and modifications were therefore made that resulted in control to ±2°F. 200 sec fuel oil was delivered to the burner at a temperature of about 150°F, and 900 sec oil at about 220°F. The oil pressure was maintained at 5 lb/sq. in. gauge.

Table 1.—*Properties of Fuel Oil* (200 *and* 900 *sec*).

Properties	200 sec	900 sec
1	2	3
General;		
Viscosity, Redwood No. 1 at 100°F ..	169	850
Specific Gravity	0·948	0·968
Flash-point (°F)	230	230
Pour-point (°F)	+10	+15
Calorific Value, Gross (B.t.u./lb) ..	18,340	18,250
Calorific Value, Net (B.t.u./lb.) ..	17,240	17,230
Ash (per cent by weight)	0·02	0·03
Sediment (per cent by weight)	0·02	0·02
Water content (per cent by weight) ..	0·05	0·10
Chemical Composition;		
Hydrogen (per cent by weight)	11·6	10·8
Carbon (per cent by weight)	85·5	85·6
Sulphur (per cent by weight)	3·0	3·7

Typical properties of the 200 sec and the 900 sec fuel oil used were assessed by the oil supplier and are given in Table 1. The sulphur content of the oil used for work on scaling of metal was determined, and these results are given in Table 2.

Table 2.—*Sulphur Analysis of Fuel Oil* (200 *sec*).

Fuel Oil Drums		Average Sulphur (Per Cent by Weight)
Group	Number Used	
1	2	3
1	5	2·43 ±0·06
2	6	3·25 ±0·07
3	5	3·15 ±0·05
4	5	3·14 ±0·04

Table 3.—*Properties of Town Gas.*

Property	G4 Town Gas
1	2
General;	
Specific Gravity	0·455
Wobbe Number	737
Aeration Number	73
Calorific Value, Gross (B.t.u./cu. ft.) ..	500
Calorific Value, Net (B.t.u./cu. ft.) ..	450
Chemical Composition;	
Carbon dioxide (per cent by volume) ..	3·2
Oxygen (per cent by volume)	0·7
Nitrogen (per cent by volume)	6·9
Carbon Monoxide (per cent by volume) ..	13·1
Hydrogen (per cent by volume)	51·2
*Hydrocarbons (per cent by volume)—	
C_nH_{2n+2}	21·7
C_nH_{2n}	3·2
Sulphur gr/100 cu. ft	22·4

* C_nH_{2n+2} and C_nH_{2n} are given as $C_{1\cdot67}H_{4\cdot59}$ and $C_{2\cdot33}H_{4\cdot70}$ respectively.

Gas

The town gas supply to the burner was governed to 2½ in. w.g., and metered. The average composition of the gas is given in Table 3.

Air

Primary air was supplied at about 25 in. w.g. Air rates to the burner, when required, were measured by means of an orifice meter. This, in conjunction with the measurement of the carbon dioxide content of the flue gas and the combustion equations given in the Appendix, enabled an estimate of the leakage of air into the furnace to be made by difference.

Secondary air, apart from the leakage air, was allowed to be induced into the furnace, if required, through the secondary air port (x) (Figure 1) of the furnace and the air register of the burner.

(D) "Hammer Test" Apparatus

In hot working, the metal is deformed and then usually allowed to cool in air. The scale that remains firmly attached to the metal may be defined as "adherent scale". The quantity of adherent scale depends on the conditions of heating and on the treatment to which the hot metal has been subjected. Since no standard test existed, it was necessary to develop a "hammer test", in which the treatment to which the hot metal is subjected is standardized, in order to compare the quantity of adherent scale resulting from various treatments. The "hammer test" apparatus used is shown in Figure 3. It consisted of a cylindrical steel weight of 23 lb

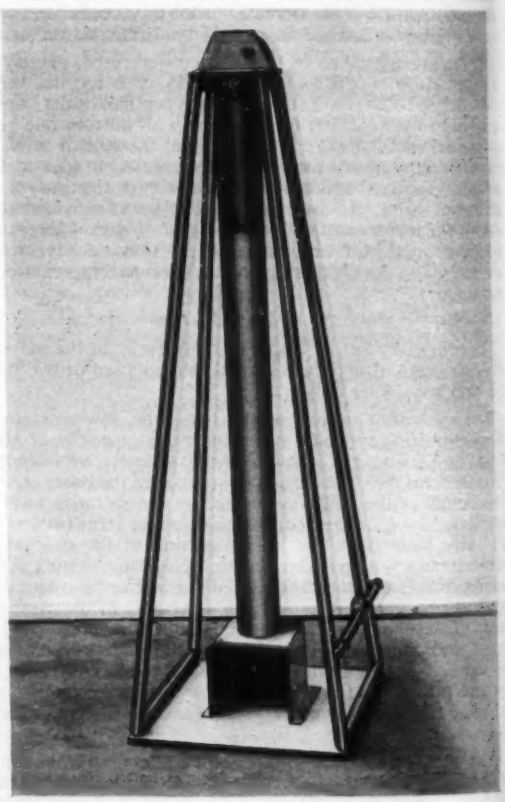


Figure 3.—*Apparatus for "Hammer Test".*

suspended in a metal tube guide by means of a rope running over a pulley. The height from the base of the weight to the platform was 2 ft 9 in. The test was carried out by holding the hot scaled sample, which was 2 in × 4 in. × ¼ in. in size for bright mild steel and 2 in. × 2 in. × ¼ in. for special steels, on its 2 in. × ¼ in edge on the platform with tongs; the weight was then allowed to drop on it from its full height. The impact of the weight deformed the sample and shattered the scale. Scale remaining on the sample was regarded as "adherent" and the quantity of this scale was determined as a loss in weight of the sample on descaling it by the process described in Section VIII(D).

VI BURNER PERFORMANCE

Before commencing work on the effect of the various combinations of town gas and oil on heated steels, some work was done to assess the performance obtainable from the burner. A smoke meter developed by the Shell Petroleum Company[32] was employed for testing combustion of oil. This meter is of the constant-volume type in which the combustion gases are drawn through a disc of filter paper and the discoloration produced was visually matched against the Shell Smoke Scale numbered from 0 (white) to 9 (black). The maximum permissible smoke was given by No. 5 on this scale, above which the combustion of oil was considered unsatisfactory.

This work can be considered under three headings.

(A) SELF-PROPORTIONING

The burner used was of the self-proportioning type, the intention being that the air : fuel ratio is maintained constant when the heat input is altered by means of the operating lever (A) (Figure 2). Tests were carried out, in the 10 ft × 3 ft 6 in. × 3 ft 6 in. furnace, to examine the self-proportioning of the burner, by measuring the fuel and air rates; the results of this test are shown graphically in Figure 4. The burner is reasonably self-proportioning. For town gas and combined fuel, it is self-proportioning only over smaller ranges of heat input than for fuel oil. The gas : oil ratio remains approximately constant at high heat input.

Figure 4 indicates a discrepancy between the measured delivery of air and that calculated on the basis of flue gas analysis. This fact naturally directs attention to the problem of excess air control.

(B) EXCESS AIR

Since it was a cardinal feature of the claims made for the combined flame, that the addition of a relatively minor proportion of town gas to an oil flame would permit an appreciable reduction in the minimum excess air required for combustion of oil without smoke formation, it was clearly necessary to control the excess air entering the furnace. The first step was the sealing of the furnace walls by application of a proprietary refractory coating on the hot face, and the closure of all inspection ports, *etc.*, and this was done before the minimum excess air requirement was investigated.

The results of the investigation are presented in Table 4 Trial 1 shows that it is practically impossible to maintain a stable oil flame under the conditions of low furnace temperature (600° to 650°C) and large combustion-chamber volume (120 cu. ft), unless secondary air is allowed to enter the furnace. When the flame was stabilized by this means, the minimum excess air was found to be about 17 per cent. At higher furnace temperatures (860° to 940°C) in trial 2, it was possible to burn oil satisfactorily without the stabilizing influence of the secondary air, but again a minimum of about 17 per cent of excess air was necessary. The governing factor for the minimum excess air requirement was the flame stability, for with a supply of 17 per cent of excess air the flame was just stable, while the Shell Smoke Scale reading was well below the limiting value of 5. Similar conclusions may be drawn for the 900 sec fuel oil from trial 4.

When the combustion chamber was reduced to 20 cu. ft,

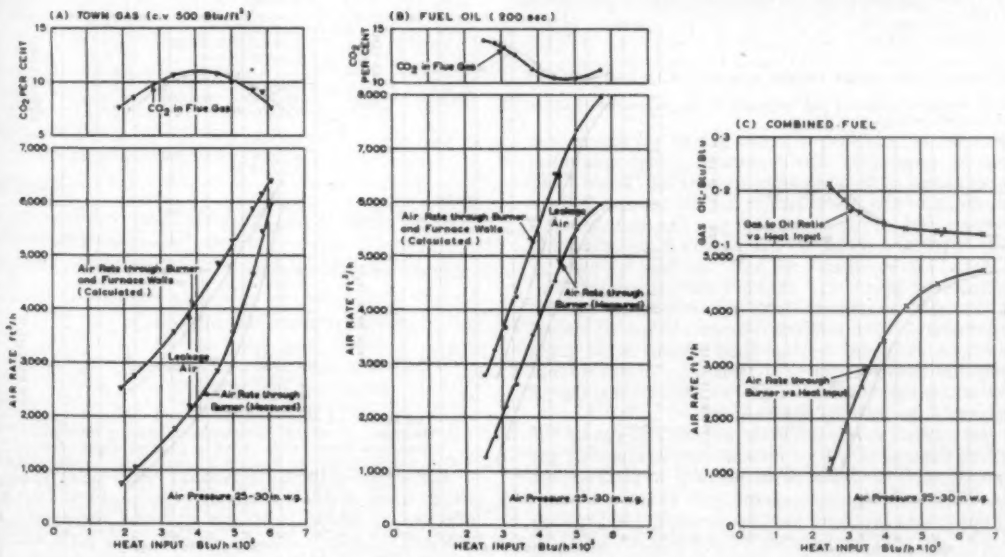

(A) TOWN GAS (c.v. 500 Btu/ft³)
(B) FUEL OIL (200 sec)
(C) COMBINED FUEL
CO₂ PER CENT
CO₂ in Flue Gas
AIR RATE ft³/h
Air Rate through Burner and Furnace Walls (Calculated)
Leakage Air
Air Rate through Burner (Measured)
Air Pressure 25-30 in. w.g.
HEAT INPUT Btu/h ×10³
GAS OIL-Btu/Btu
Gas to Oil Ratio vs Heat Input
Air Rate through Burner vs Heat Input

FIGURE 4.—*Burner Performance.*

particularly at the temperatures used for heating of ferrous metals for forging (trials 6 and 8), a satisfactory combustion of oil was achieved with a minimum excess air of 1 to 2 per cent; the limiting factor for minimum excess air under these conditions was the Shell Smoke Scale value.

TABLE 4.—*Minimum Excess Air Requirement.*

Run	Grade of Fuel Oil (Sec.)	Furnace Temp. (°C)	Heat Input (B.t.u./hr) Fuel Oil	Heat Input (B.t.u./hr) Town Gas	Heat Supplied by Town Gas (per Cent)	Shell Smoke No.	Flame Stability	Excess Air (per Cent)
1	2	3	4	5	6	7	8	9
Combustion Chamber Volume—120 cu. ft.								
1a	200	600	450,000	—	—	—	Unstable	—
*b		600	450,000	—	—	4	Stable	30·5
*c		650	450,000	—	—	5	,,	16·7
2a		860	555,000	—	—	2	Just Stable	16·7
b		860	555,000	17,000	3·0	4	Slightly Unstable	8·5
c		880	555,000	23,700	4·1	4	Stable	5·9
d		900	565,000	35,600	5·9	4½	,,	3·9
e		920	565,000	55,250	8·9	5	,,	<1
f		940	565,000	66,500	10·5	7	,,	—
3a	900	850	433,000	—	—	—	Unstable	—
b		850	433,000	86,500	16·7	4	,,	3·7
†c		850	433,000	86,500	16·7	4	Stable	3·6
†d		860	433,000	32,500	7·0	4	,,	3·6
†e		860	433,000	25,000	5·5	—	Unstable	—
4a		860	451,000	—	—	2	Just Stable	18·4
b		880	451,000	9,900	2·2	3	Slightly Unstable	12·3
c		910	451,000	18,000	3·8	3	Stable	8·5
d		920	442,000	31,000	6·6	3	,,	7·3
e		930	442,000	40,000	8·3	3	,,	6·3
f		940	442,000	50,000	10·2	5	,,	<1
g		950	442,000	60,000	12·0	9	,,	—
Combustion Chamber Volume—20 cu. ft.								
5a	200	840	334,000	—	—	3½	Stable	18·6
b		860	342,000	—	—	4	,,	15·7
c		930	390,000	—	—	5	,,	2·5
6a		1,160	421,000	—	—	4	Stable	7·0
b		1,190	555,000	—	—	5	,,	1·3
7a	900	880	301,000	—	—	3	Stable	8·2
b		930	390,000	—	—	5	,,	5·4
8a		1,170	504,000	—	—	2	Stable	18·4
b		1,220	524,000	—	—	5	,,	2·1

* Air was allowed to be induced through secondary air inlet (x), shown in Figure 1.
† Air supply through the burner was increased by an amount equal to the stoichiometric air for combustion of gas.

The effect of the addition of town gas to oil flames was investigated for conditions that demanded a high minimum percentage of excess air for the combustion of oil. Trials 2 and 4 give the results of this investigation for 200 sec and 900 sec fuel oil respectively. Trial 2 showed that the simultaneous combustion of gas and oil led to a reduction in the minimum excess air from 17 to less than 1 per cent; the heat supplied by gas to produce the effect was about 9 per cent of the total heat load. Similar conclusions may be reached for 900 sec fuel oil from trial 4. The minimum excess air for combined gas/oil fuel was governed by the Shell Smoke Scale value and not by the flame stability. It was also observed that addition of a small percentage of gas to an oil flame that is just stable upsets the stability of the flame.

Trial 3 was carried out to assess the influence of gas on the stability of oil flames. It will be noticed that addition of gas alone to an unstable oil flame does not help to stabilize the flame, but, if the stoichiometric quantity of air for the combustion of gas is also supplied, then the flame is stabilized. A minimum of 7 per cent heat supply by gas was necessary to stabilize the oil flame; below this limit, the flame remained unstable.

It should be noted that this result is achieved by feeding about 70 per cent of the stoichiometric quantity of air to the burner, the remaining 30 per cent arising from leakage through walls, *etc.*

(c) Adventitious Air

The significance of these results is that they show that, given correct combustion chamber size and control of adventitious air, the burner used can burn a 100 per cent oil flame, of either 200 sec or 900 sec oil, satisfactorily with virtually no excess air. Thus, under certain circumstances, the claim that the combined town gas/fuel oil flame can permit an otherwise unattainable reduction in excess air is seen to be invalid.

This leaves for consideration the further suggestion that, under circumstances where, for one reason or another, a perfect marriage between burner and combustion chamber is not, or cannot be, achieved, an addition of town gas to an oil flame will be helpful in burning up any uncontrollable excess air. Some support for this can be seen in Table 4, and further tests were carried out in the 5 ft × 3 ft 6 in. × 3 ft furnace to study the point.

Arrangements were made to allow extra air to enter the furnace at one of three places, referred to as (x), (y) and (z) on Figure 1.

In each test, the adventitious air was controlled to give about 20 per cent excess air with a fuel-oil flame, and an increasing amount of gas was burned simultaneously with the oil until the Shell Smoke Scale limit of 5 was reached. The gas was then turned off and the oil load increased until the Shell Smoke Scale limit of 5 was again reached. Similar experiments were carried out with about 40 per cent excess air

TABLE 5.—*Reduction of Adventitious Air.*

Run	Position of Air Inlet (Fig. 1)	Heat Input (B.t.u./hr) Fuel Oil	Heat Input (B.t.u./hr) Town Gas	Heat supplied by Town Gas (per Cent)	Excess Air (per cent)
1	2	3	4	5	6
Fuel Oil (200 sec)					
1a	X	521,000	—	—	22·4
b		530,500	70,400	12	1·1
c		676,000	—	—	0·9
2a	Y	512,000	—	—	23·7
b		515,000	43,600	10	1·7
c		620,000	—	—	1·2
3a	Z	564,000	—	—	21·4
b		586,000	106,000	16	0·9
c		690,000	—	—	1·2
4a	X	396,500	—	—	40·3
b		422,500	117,500	22	1·0
c		539,000	—	—	0·6
5a	Y	407,000	—	—	42·6
b		417,500	144,000	26	0·3
c		546,500	—	—	0·4
6a	Z	436,000	—	—	42·5
b		431,000	150,000	26	1·6
c		567,000	—	—	0·9
Fuel Oil (900 sec.)					
7a	X	462,200	—	—	18·9
b		451,200	78,500	15	0·9
c		592,000	—	—	3·1

a—Run for fuel oil only.
b—Heat input of run "a" increased by addition of town gas.
c—Heat input of run "a" increased by addition of more fuel oil.

The results of these experiments are given in Table 5. From these values it will be seen that extra oil was found to be as effective as added town gas in using the excess air. The position at which the air entered had little effect on the results, due, doubtless, to the strong recirculating currents in the furnace.

VII PROGRAMME FOR WORK ON METAL HEATING

Having established the performance of the burner, a programme of work was drawn up to study the metallurgical aspects of the effect of the various flames on steels heated to forging temperature. Forging temperatures were chosen as likely to produce the most severe attack on the metal. The variables involved are the type of steel, the period of heating, the type of fuel and excess air, of which the last two together determine the composition of the furnace atmosphere in contact with the steel.

(A) Selection of Steels

It was envisaged that a large number of samples would be required and, therefore, ordinary bright mild steel was selected for the majority of the trials. This steel has a comparatively smooth and clean surface, is cheap and readily available. In addition, samples of known composition were made available of two plain carbon steels having low (En 32B) and medium (En 8) carbon content respectively, and one alloy steel (En 26 Ni-Cr-Mo). These are referred to in this Paper as "special steels", but, since the quantities available were limited, the results for these steels were obtained using a fewer number of samples. The analysis of the special steels is given in Table 6.

Table 6.—*Analysis of Special Steels.*

Constituent	Analysis (per Cent by Weight)		
	"35" Carbon Steel (B.S.970–En8)	Carbon Case Hardening Steel (B.S.970–En32B)	Ni-Cr-Mo Steel (High C) (B.S.970–En26)
1	2	3	4
C	0·34	0·12	0·42
Si	0·29	0·22	0·28
Mn	0·75	0·69	0·62
S	0·045	0·054	0·016
P	0·037	0·039	0·015
Ni	0·08	0·09	2·54
Cr	0·07	0·06	0·71
Mo	0·05	0·05	0·55
W	0·02	<0·02	Nil
V	0·03	<0·03	<0·03
Ti	0·02	<0·02	Nil
Co	0·01	<0·01	Nil
Cu	0·11	0·23	0·16
Al	0·02	0·014	Nil
Sn	0·02	<0·02	Nil
Pb	0·05	<0·05	Nil

(B) Experimental Plan

Bright Mild Steel

The experiments were conducted according to the following plan, at a temperature of 1,200° ±10°C.

The scaling loss was determined for the following conditions of heating:—

Fuel	0, 2·5, 14, 25 and 100 per cent of the total heat input as town gas, the remainder (if any) being 200 sec fuel oil.
Excess air	2, 5, 10 and 30 per cent.
Period of heating ..	½, 1, 2, 3 and 4 hr.

The five fuels and four levels of excess air necessitated 20 runs. Eleven samples were used for each run, two being removed for test after each period of heating. The extra one, which was heated for 2 hr, was retained for visual examination of the scale. In order to test the repeatability, the runs with 5 and 30 per cent excess air, and for ½, 2 and 4 hr, using 100 per cent oil, 100 per cent gas, and 14 per cent gas, a total of 6 runs, were repeated.

The quantity of adherent scale was determined for the following conditions of heating:—

Fuel	0, 14 and 100 per cent of the total heat input as town gas, the remainder (if any) being 200 sec fuel oil.
Excess air	2, 5, 10 and 30 per cent.
Period of heating ..	½, 2, and 4 hr.

In this series, the runs for each period of heating were carried out separately. Thus, three fuels, four levels of excess air and three periods of heating gave 36 runs. At first, 10 samples per trial were used for a 2 hr heating period, but this was subsequently reduced to five per trial after establishing that the "hammer test" for adherence of scale was satisfactory.

These experiments were repeated, but this time only the ½ hr runs were carried out separately.

Chemical Analysis of Scale. Runs were carried out under the conditions given above, but only with 5 and 30 per cent excess air to provide samples of scale for chemical analyses. Samples for all three periods of heating were obtained from single runs, so that, in all, six runs were necessary. 2 in. × ¼ in. diameter rods in silica dishes were used for this purpose.

Special Steels

The *scaling loss*, the *adherence of the scale* and the *decarburization effects* were determined for the following conditions of heating:—

Fuel	0, 14 and 100 per cent of the total heat input as town gas, the remainder (if any) being 200 sec fuel oil.
Excess air	2, 5, 10 and 30 per cent.
Period of heating ..	½, 2 and 4 hr.

The three fuels and four levels of excess air constitute 12 runs. Nine samples of each of the three types of steel were used for each run, three samples for each period of heating, of which one was retained for visual examination of the scale and for the determination of decarburization.

VIII PROCEDURE

The general procedure adopted for the experiments on metal heating was as follows:—

The furnace, which was now 5 ft × 3 ft 6 in. × 3 ft with bottom flue outlet, was heated by gas to a temperature of about 800°C, and the heating was then continued by the appropriate fuel for the particular run. The excess air was controlled to the required value and, when the furnace had reached 1,200°C, the steel samples were placed on the hearth of the furnace within the limits marked "a" and "b" on Figure 1. Samples were removed at appropriate intervals and treated, as described below, for the determination of the scaling loss, the adherence of the scale and decarburization.

(A) Temperature

The temperature of the furnace was measured at the position T shown in Figure 1, by a Platinum—13 per cent Rhodium Platinum thermocouple. A preliminary experiment, carried out with a steel sample having a thermocouple embedded in it, showed that the sample when inserted into the hot furnace

reached furnace temperature within a short time. This was thereafter taken as a measure of sample temperature. Throughout the experiments, the furnace temperature was measured and controlled to 1,200° ±10°C. It fell rapidly below this value on opening the furnace door for the removal of the samples, but was soon regained.

(B) Furnace Atmosphere

The results of a survey of the carbon dioxide content of the furnace atmosphere are given in Table 7, from which it will be seen that it was fairly uniform, particularly in the region where the steel samples were placed. The excess air was set by adjusting air and fuel supply and using the carbon dioxide concentration of the furnace atmosphere determined at point 7 in plane BB (Figure 1) and the combustion chart, Figure 23.

Table 7.—*A Survey of Carbon Dioxide Content of Furnace Atmosphere from Fuel Oil* (200 *sec*).

*Position of Sampling Point in Plane	Carbon Dioxide (per Cent)	
	Plane A—A	Plane B—B
1	2	3
1	15·4	15·9
2	15.7	16·0
3	15·6	15·7
4	15·9	15·8
5	†N.D.	15·9
6	15·7	15·6
7	16·0	16·0
8	15·9	15·8
9	15·9	†N.D.

* Sampling points refer to Figure 1.
† N.D.—not determined.

The composition of the furnace atmosphere was then calculated from the excess air and the equations given in the Appendix, and the results are given in Table 8. The sulphur dioxide concentration of the furnace atmosphere obtained from the chart assumes the oil has a sulphur content of 3 per cent. A correction should be applied to the sulphur dioxide concentration for deviation (Table 2) from this value in the determined sulphur content of oil.

Table 8.—*Composition of Furnace Atmosphere in the Experiments on the Scaling of Steels calculated from Combustion Equations* (*Appendix*).

Fuel	Excess Air (per Cent)	Constituents (per Cent by Volume)				
		CO_2	O_2	H_2O	N_2 by difference	*SO_2 × 10^{-2}
1	2	3	4	5	6	7
Fuel Oil (200 sec)	2	13·90	0·39	11·05	74·7	17·90
	5	13·48	0·84	10·76	74·9	17·45
	10	12·90	1·81	10·30	75·0	16·70
	30	11·00	4·63	8·79	75·6	14·21
Combined Fuel: 14 per cent Town Gas	2	13·26	0·39	12·40	74·0	15·60
	5	12·90	0·93	12·06	74·1	15·22
	10	12·35	1·79	11·55	74·3	14·58
	30	10·56	4·59	9·88	75·0	12·45
Town Gas	2	9·35	0·36	20·90	69·4	0·0750
	5	9·13	0·89	20·38	69·6	0·0733
	10	8·75	1·66	19·58	70·0	0·0704
	30	7·56	4·31	16·90	71·2	0·0610

* SO_2 is based on a figure of 3 per cent sulphur in the fuel oil and should be corrected for the variation in the sulphur content of the fuel (Table 2).

(C) Preparation of Steel Samples

The selection of steels used for the experiments is considered in Section VII. The bright mild steel samples were cut to a size 2 in. × 4 in. × ¼ in. from a 2 in. × ¼ in. strip; each sample weighed approximately 250 g.

The special steel samples were cut from 2 in. square rolled billets to a size of 2 in. × 2 in. × ¼ in., and polished all over. These samples weighed about 110 to 140 g.

All the samples were weighed and degreased in trichlorethylene before heating. The samples were supported in refractory blocks, as shown in Figure 5. Under certain conditions of firing, in which slagging of the refractories resulted, difficulties were experienced in supporting the samples in this manner. However, the fact that, even when this occurred, the descaled samples were of uniform thickness indicated that slagging of refractories in contact with the samples had a negligible effect on scale formation.

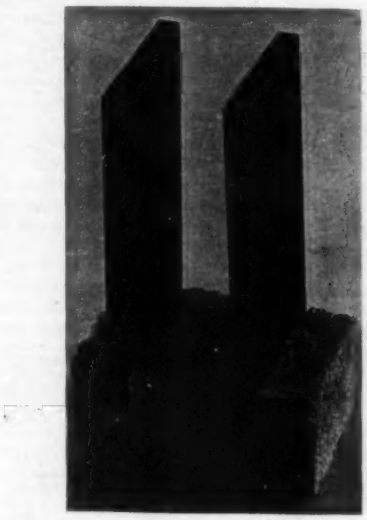


Figure 5.—*Method of Support for Samples.*

(D) Scaling Loss

The bright mild steel samples were quenched in water, which detached a large proportion of the scale; the remaining scale was removed by pickling in boiling 40-per-cent-hydrochloric acid solution for a period of 2 to 3 min., depending on the type of scale. This procedure failed to descale completely the samples with very adherent scale, and these were therefore subjected, after pickling, to mechanical treatment such as chipping and wire-brushing. The scaling loss was determined as the difference in cg/sq. cm between the initial weight of the samples and the final weight of the descaled samples. A blank test on an unscaled sample showed that loss in weight of steel due to attack by the pickling solution was negligible.

(E) Quantity of Adherent Scale

A second set of bright mild steel samples were partly descaled by the " hammer test " described in Section V. The scale that still remained firmly attached to the samples was considered to be the adherent scale, and it was removed by the methods described above. The quantity of adherent scale was determined as the difference in weight between the deformed samples and the descaled samples, and expressed in cg/sq. cm.

The special steels were weighed initially, again after the " hammer test ", and finally after descaling, so that both the scaling loss and the adherent scale were obtained from the one sample.

(F) Analysis of Scale

The samples were weighed before and after heating and finally after descaling. The bulk of the scale was removed by mechanical means and the thin layer of scale left on the steel surface was removed chemically during the determination of the sulphur on the samples. The scale removed mechanically was powdered to pass through a 60-mesh sieve and analysed volumetrically for ferrous and total iron. The sulphur on the steel samples from which the scale had been mechanically removed was determined gravimetrically. This involved immersing the samples in acid, so that they were at the same time completely descaled. The sulphur in the powdered scale was determined only for steels heated for 4 hr by a fuel oil flame and a gas flame.

(G) Decarburization

The investigation of decarburization accompanying scale formation was undertaken for the special steels. A small piece was cut from each sample and fully hardened by reheating in salt baths to 850°C (En 8 and En 26) or 900°C (En 32B), and quenching in oil (En 8 and En 26) or water (En 32B). All the samples from each type of steel were treated at the same time with a control sample, which was not previously heated in the furnace. A hardness traverse was done from the edge inwards on the cut surface, using Vickers Hardness Apparatus (5 kg load), and the extent of decarburization, if any, was indicated by the change in hardness.

IX RESULTS

(A) Accuracy of Experiments

To show the accuracy of the experimental results on scaling of steel, Tables 9 and 10 have been prepared for 5 and 30 per cent excess air, the samples being heated by fuel oil (200 sec), town gas and combined fuel for ½, 2 and 4 hr heating periods. This covers the type of run that is most difficult to control, namely, that with the combined fuels in which furnace temperature and atmosphere had to be controlled by altering the two fuel rates separately, while at the same time maintaining a constant ratio of the heat input of the two fuels. Tables 9 and 10 cover also the runs in which low-melting-point scale is formed, i.e., fuel oil and combined fuel at 5 per cent excess air.

Scaling Loss

The extent of agreement between duplicate steel samples used in the same run for determination of scaling loss is shown in Table 9, by the deviation from the average of two results. This deviation never exceeded ±2·0 cg/sq. cm. A comparison of the results of the two series of experiments show that the repeatability of the experiments may also be regarded as satisfactory. The range of results for the four determinations, two for each series of experiments, indicate the overall scatter. The maximum range is 4 cg/sq. cm.

Quantity of Adherent Scale

Table 10 shows the results of experiments performed to determine the quantity of adherent scale, for the conditions of heating stated above. The degree of scatter of results is indicated by the standard deviation. The maximum standard deviation is 2·6. It should be noted that the standard deviation is generally large when fuel oil or combined fuel is used at 5 per cent excess air and also for 2 and 4 hr of heating. It may be concluded that the "hammer test" for assessment of quantity of adherent scale is satisfactory.

Table 9.—*Results of Scaling Loss, Bright Mild Steel at 1,200°C.*

Run	Fuel	Excess Air (per Cent)	Heating Period (hr)	Scaling Loss (cg/sq. cm.) Series 1 Average*	Series 1 Deviation (±)	Series 2 Average*	Series 2 Deviation (±)	Series 1 and 2 Range
1	2	3	4	5	6	7	8	9
1	Fuel Oil (200 sec)	5	½	28·1	0·4	29·8	0·9	1·8
			2	70·6	1·3	66·8	0·8	2·6
			4	100·3	0·3	103·6	1·1	2·2
2		30	½	28·0	0·2	26·4	0·3	0·6
			2	63·3	0·7	65·3	0·1	1·4
			4	91·8	0·8	88·5	0·8	1·6
3	Combined Fuel: 14 per Cent Town Gas	5	½	23·7	0·6	24·5	1·5	3·0
			2	50·4	1·0	54·4	2·0	4·0
			4	85·0	1·0	88·0	1·5	3·0
4		30	½	26·8	0·2	26·4	0·1	0·4
			2	63·2	0·7	59·7	1·1	2·2
			4	94·2	0·1	91·3	1·5	3·0
5	Town Gas	5	½	17·8	0·3	16·2	0·8	1·6
			2	45·2	0·4	44·2	0·5	1·0
			4	80·8	0·8	77·6	0·6	1·6
6		30	½	29·0	0·3	29·4	0·2	0·6
			2	63·7	0·2	66·8	0·8	1·6
			4	97·4	1·1	100·4	1·5	3·0

* Average of two samples for each period of heating.

Table 10.—*Results of Quantity of Adherent Scale, Bright Mild Steel at 1,200°C.*

Run	Fuel	Excess Air (per Cent)	Heating Period (hr)	Quantity of Adherent Scale (cg/sq. cm) Series 1 Average*	Series 1 Standard Deviation	Series 2 Average†	Series 2 Standard Deviation	Series 1 and 2 Average	Series 1 and 2 Deviation (±)
1	2	3	4	5	6	7	8	9	10
1	Fuel Oil (200 sec)	5	½	6·8	0·4	7·9	0·4	7·4	0·5
2			2	11·4	2·6	10·6	0·4	11·0	0·4
3			4	14·7	2·3	14·6	2·0	14·7	0·1
4		30	½	4·4	0·2	5·4	0·6	4·9	0·5
5			2	6·7	0·6	6·4	0·6	6·6	0·2
6			4	9·9	0·7	9·6	1·1	9·8	0·2
7	Combined Fuel: 14 per Cent Town Gas	5	½	7·0	0·6	7·9	1·0	7·5	0·5
8			2	11·4	1·7	11·8	1·3	11·6	0·2
9			4	14·3	1·5	14·0	0·5	14·2	0·2
10		30	½	3·9	0·5	5·0	1·0	4·5	0·6
11			2	8·7	0·5	8·1	0·5	8·4	0·3
12			4	7·0	0·8	5·9	1·2	6·5	0·6
13	Town Gas	5	½	3·1	0·4	3·4	0·2	3·3	0·2
14			2	4·1	0·3	4·4	0·4	4·3	0·2
15			4	7·0	0·3	6·0	0·3	6·5	0·5
16		30	½	4·1	0·8	3·9	0·8	4·0	0·1
17			2	6·6	0·6	6·9	0·5	6·8	0·2
18			4	3·4	0·9	4·2	0·3	3·8	0·4

* Average of five samples for each period of heating except 2 hr heating periods in which 10 samples were used.
† Average of five samples for each period of heating.

(B) Scaling Loss *versus* Time

Bright Mild Steel

The effect of the duration of heating at constant levels of excess air on the scaling loss for bright mild steel heated to 1,200°C by 200 sec fuel oil, town gas and combinations of these two fuels, is shown in Figure 6, which shows that the scaling loss increases with time for all the fuels and levels of excess air studied. The values of scaling loss obtained for the

combined fuels, containing 2·5 and 25 per cent gas, are shown in Figure 6, but the curves for these fuels have been omitted to avoid confusion.

Conclusions may be drawn from Figure 6 on the effect of the scaling loss of the addition of town gas to fuel-oil flames, but as in practice the time of heating of metal for forging is generally decided by considerations other than that of scale formation, such as size of work piece, it would be more appropriate to draw these conclusions from Figure 8, which relates excess air to scaling loss for the various fuels at constant periods of heating. These curves are discussed later. After study of Figure 6, it was decided that investigation of scaling loss for the special steels and the quantity of adherent scale for all the steels be limited to 0, 14, and 100 per cent town gas flames and excess air values of up to 30 per cent.

The general shape of scaling loss *versus* time curves (Figure 6) agrees with theoretical and experimental work on the oxidation of metals[14,31], and this may be taken as support for the experimental techniques used in assessing the scaling loss. These graphs are parabolic for the initial period of heating of ½ to 1 hr, and thereafter continue as such or change to straight lines. The parabolic curve, particularly at the beginning of the heating periods, is typical of compact types of scale in which the rate of diffusion of iron or oxygen through the scale is primarily governed by the thickness of the scale layer which increases with time of heating; the linear part of the curves is said to indicate the formation of porous types of scale.

Special Steels

The scaling loss *versus* time curves for the special steels are not shown in this Paper, but can be obtained for each steel from the results plotted in Figures 10, 12 and 14 respectively. These graphs will be found to resemble in their general shape the graphs for bright mild steel (Figure 6).

(c) Quantity of Adherent Scale *versus* Time

Bright Mild Steel

The effect of the duration of heating at constant levels of excess air on the quantity of adherent scale for bright mild steel is shown in Figure 7. This shows that the quantity of adherent scale generally increases with time, but, for certain conditions of heating, it is reduced on increasing the time of

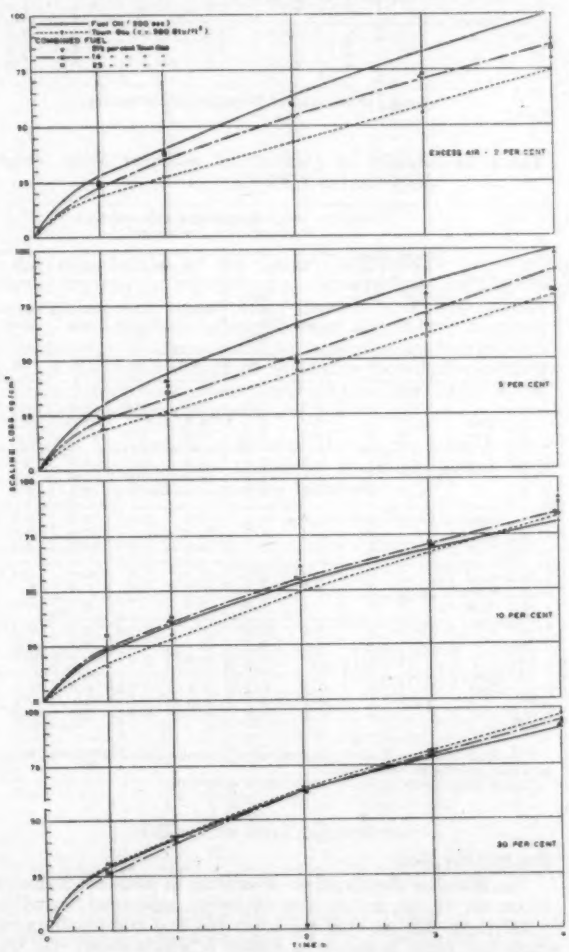


FIGURE 6.—*Scaling Loss* versus *Time, Bright Mild Steel at* 1,200°*C.*

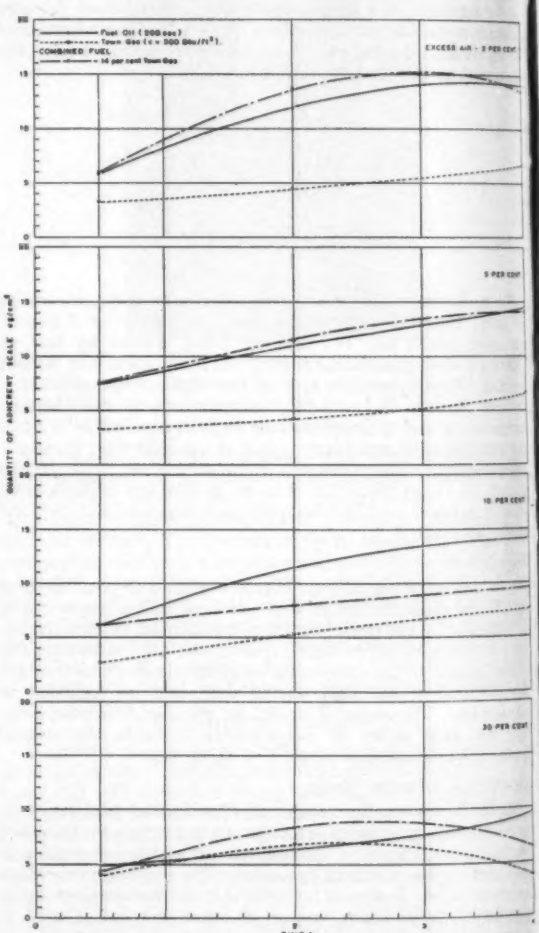


FIGURE 7.—*Quantity of Adherent Scale* versus *Time, Bright Mild Steel at* 1,200°*C.*

heating from 2 to 4 hr. It would be more appropriate, for the reasons previously given, to consider the effect of different fuels on the quantity of adherent scale as shown in Figure 9, which relates the quantity of adherent scale to excess air for constant periods of heating. This will therefore be considered later.

Special Steels

Adherent scale *versus* time curves for the special steels are not shown in this Paper but can be obtained for each steel from the results plotted in Figures 11, 13 and 15. These graphs will be found to resemble in their general shape the curves for bright mild steel (Figure 7). It will also be noticed for some conditions of heating of special steels, particularly the plain carbon steels, that there is a marked reduction in the quantity of adherent scale on increasing the time of heating from 2 to 4 hr.

(D) Scaling Loss *versus* Excess Air

Bright Mild Steel

The scaling loss *versus* excess air curves for constant periods of heating (½, 2 and 4 hr) for bright mild steel are shown in Figure 8, and the points for 2·5 and 25 per cent gas are marked.

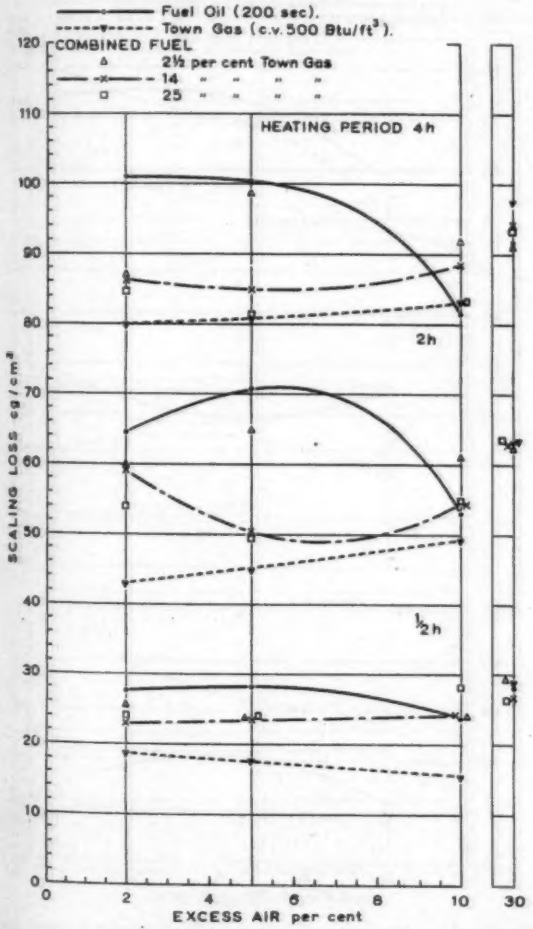


FIGURE 8.—*Scaling Loss* versus *Excess Air, Bright Mild Steel at* 1,200°*C.*

It is not possible to determine accurately the shape of the curves between 10 and 30 per cent excess air from the results at these two excess air levels, and, therefore, the excess air axis is interrupted. However, this will still enable comparison to be made of the 30 per cent excess air results with those of 2, 5 and 10 per cent excess air.

It is seen from Figure 8 that, when using 100 per cent fuel oil, a reduction in excess air from 30 to 10 per cent decreases the scaling loss a little; a further reduction in excess air to 5 per cent is accompanied by a rapid increase in the scaling loss. This increase in scaling loss is generally about 25 per cent. At 2 per cent excess air, the scaling loss is not very different from that at 5 per cent excess air. Some tendency, however, for the scaling loss to decrease as excess air is reduced below 5 per cent shows up distinctly for the 2 hr heating period. The rapid rise in the scaling loss with reduction in excess air or free oxygen is contrary to the general theory of oxidation of metal.

The results are, however, in agreement with that of Preece and Riley[21], who published the scaling behaviour of different steels including a plain carbon steel (0·13 per cent carbon), which was heated to 1,150°C for 1½ hr in a synthetic furnace

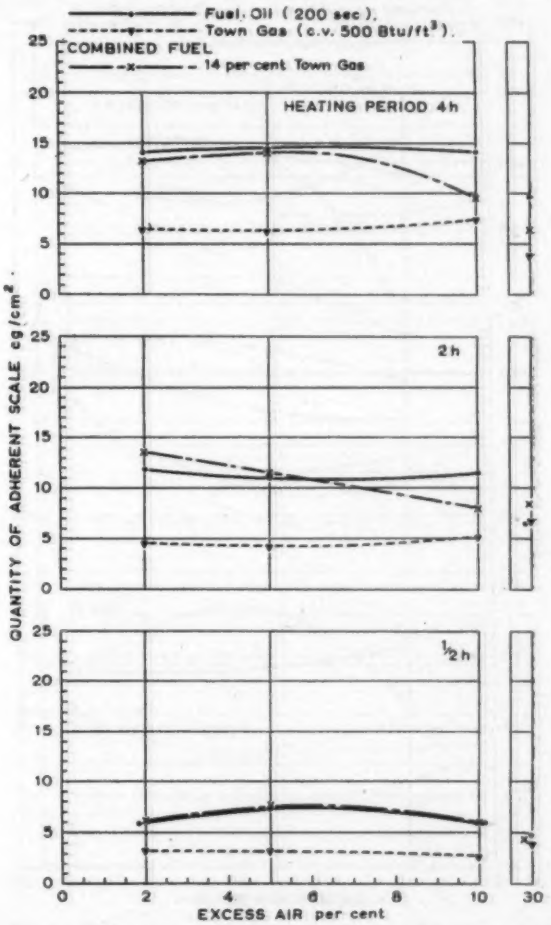


FIGURE 9.—*Quantity of Adherent Scale* versus *Excess Air, Bright Mild Steel at* 1,200°*C.*

atmosphere composed of 80 per cent of nitrogen, 10 per cent of carbon dioxide, 10 per cent of steam, and 0·2 per cent of sulphur dioxide, from which nitrogen was replaced by an increasing amount of oxygen. It was shown that maximum scaling occurred with about 1 per cent of free oxygen in the furnace atmosphere. These Authors suggested that, at low values of oxygen in a furnace atmosphere containing sulphurous gases, an iron oxide/sulphide eutectic (melting-point about 930°C) is formed at the metal-scale interface, which, being in a molten state at the forging temperature of steel, reduces the resistance to diffusion of iron, and, consequently, leads to severe scaling. As free oxygen is altered from the critical value associated with the maximum scaling of steel, the formation of the eutectic is suppressed with a resultant decrease in scaling, and at a free oxygen value of 5 per cent the scaling is reduced to that resulting from the synthetic atmosphere free from sulphur dioxide. It was shown that furnace atmosphere containing less than 0·03 per cent of sulphur dioxide behaved as normal oxidizing atmospheres toward steel without the complications of the eutectic.[20]

In the present experiments, the maximum scaling loss for a 2 hr heating period, or, by interpolation on Figure 6, for a 1½ hr heating period, occurred at 5 per cent excess air, which is equivalent to about 1 per cent of free oxygen in a furnace atmosphere (Table 8) resembling the synthetic atmosphere used by Preece and Riley. The scale formed at 2 or 5 per cent excess air had clearly melted and was responsible for slagging the refractory supports of the samples. At 10 per cent excess air, only slight evidence of semi-molten scale could be detected, and at 30 per cent excess air (i.e., 5 per cent free oxygen) the scale formed was of the normal solid type.

The scaling loss for bright mild steel heated by town gas decreased as expected with decrease in excess air. A reduction of excess air from 30 to 5 per cent reduced the scaling loss by 38, 30 and 17 per cent for ½, 2 and 4 hr of heating respectively. At 30 per cent excess air, the scaling losses for gas and oil heating are comparable; in fact, there is a tendency for gas to produce rather more scale. From the discussion above, the effect of sulphur dioxide in fuel-oil furnace atmosphere containing 30 per cent excess air may be considered to be negligible, and, therefore, a comparison of the oxidizing power of furnace atmospheres from fuel oil and town gas can be made

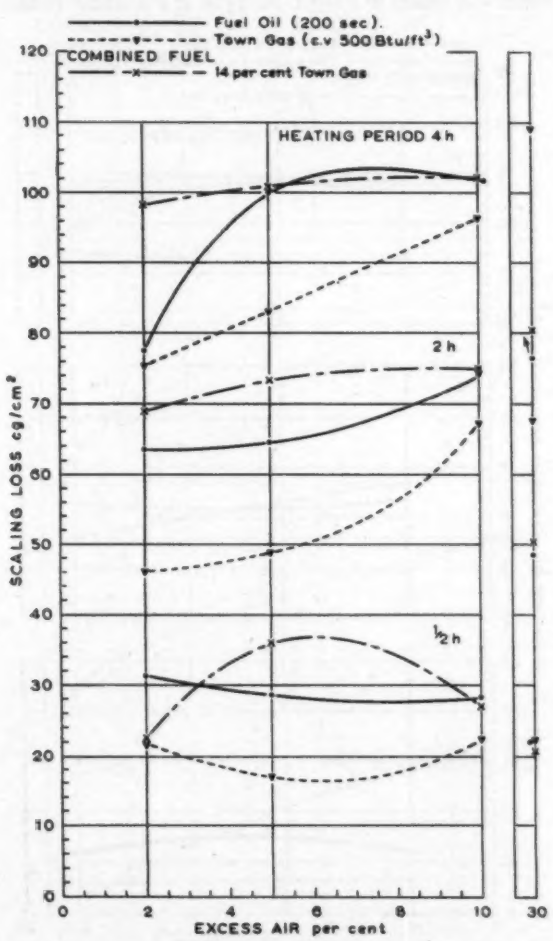


FIGURE 10.—*Scaling Loss* versus *Excess Air, Carbon Case Hardening Steel* (*B.S.* 970; *En* 32*B*) at 1,200°*C*.

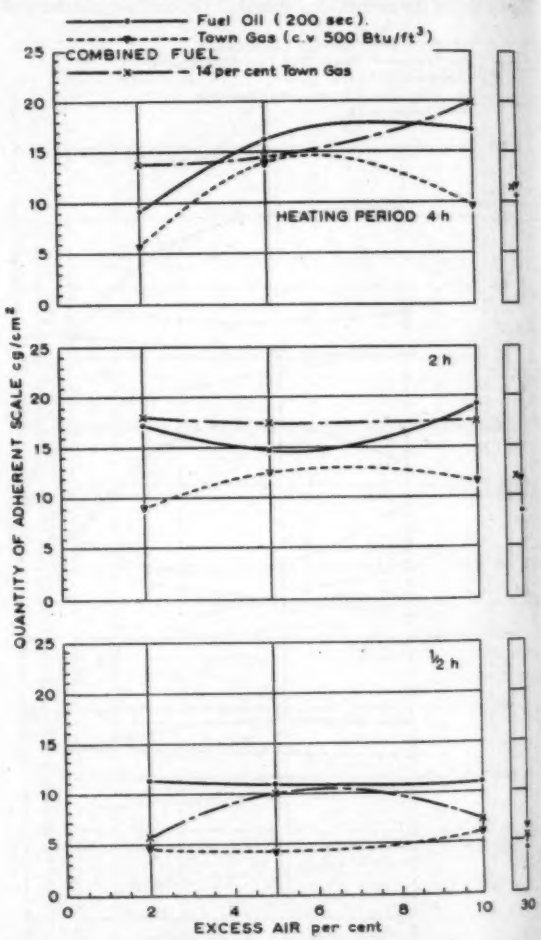


FIGURE 11.—*Quantity of Adherent Scale* versus *Excess Air, Carbon Case Hardening Steel* (*B.S.* 970; *En* 32*B*) *at* 1,200°*C*.

from the composition given in Table 8. The free oxygen content of the two atmospheres at 30 per cent excess air is nearly the same, but the steam : carbon dioxide ratio for town gas is high compared to that for fuel oil, and this may account for the tendency of gas to be more scaling than fuel oil. It has been shown that steam at high temperatures is relatively more oxidizing than carbon dioxide.[17] At low excess air, gas produced a less scaling atmosphere than oil : for example, at 5 per cent excess air the reduction in scaling loss on conversion from oil-to gas-firing is of the order of 35 per cent for ½ and 2 hr heating and about 20 per cent for the 4 hr heating.

The advantage of combined fuel over oil with respect to scaling loss was found at low excess air, particularly at 2 and 5 per cent ; in this range, the scaling loss decreases progressively as the percentage of gas increases. However, at 10 and 30 per cent excess air there is generally a small increase in the scaling loss, probably due to the greater oxidizing power of gas compared to oil. The 2 and 4 hr curves in Figure 8 show that at 5 per cent excess air the addition of 2½ per cent of gas to fuel oil makes relatively little difference to the scaling loss,

TABLE 11.—*Percentage Reduction in Scaling Loss on Increasing the Proportion of Town Gas to Fuel Oil. Bright Mild Steel Heated at 1,200°C, and 5 per cent Excess Air.*

Gas in Fuel (per Cent)	Period of Heating (hr)		
	½	2	4
1	2	3	4
2½	18	9	2
14	18	27	16
25	18	31	20
100	35	35	20

Note: In each column, reductions are related to the scale formation for 100 per cent fuel oil.

while increasing the gas to 25 per cent results in a scaling loss comparable to that of gas alone. Table 11 gives the percentages by which scaling loss is decreased at 5 per cent excess air for ½, 2 and 4 hr heating periods, as the proportion of gas in the combined fuel is increased.

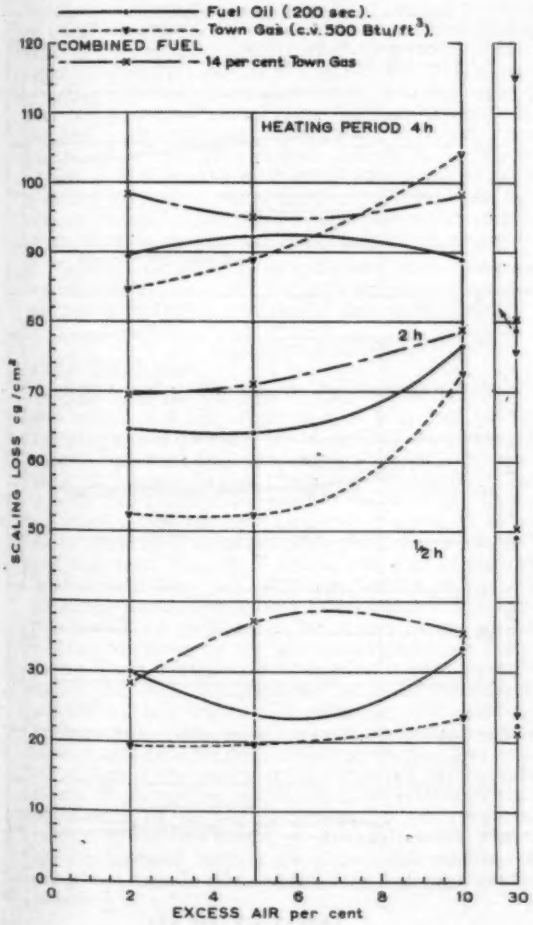


FIGURE 12.—*Scaling Loss* versus *Excess Air* "35" *Carbon Steel* (*B.S.* 970; *En* 8) *at* 1,200°*C*.

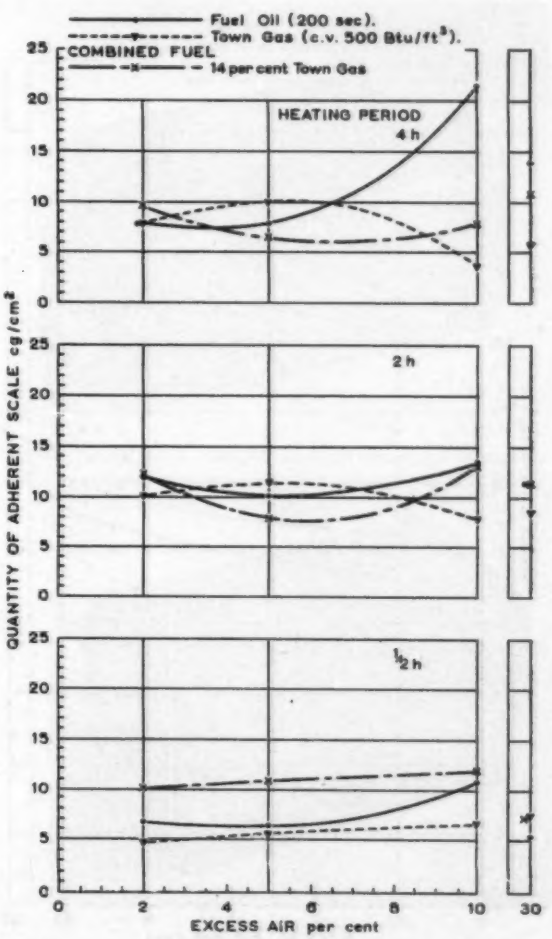


FIGURE 13.—*Quantity of Adherent Scale* versus *Excess Air*, "35" *Carbon Steel* (*B.S.* 970; *En* 8) *at* 1,200*C*.

Special Steels

The scaling loss *versus* excess air graphs for the special steels are shown in Figures 10, 12 and 14. The maximum scaling loss with fuel oil at low excess air observed for bright mild steel occurs also with the special steels, but for some conditions of heating the maximum occurs at a higher level of excess air. The scaling loss for gas heating decreases with reduction in excess air, as for bright mild steel, but not so uniformly; there is a sharp decrease as excess air is reduced from 10 to 5 per cent, particularly for 2 and 4 hr heating. The tendency for gas to be more scaling than oil at 30 per cent excess air noted for bright mild steel is very definite for the special steels. The accuracy of scaling loss determinations for the special steels should be the same as for bright mild steel, since in both cases the results are for duplicate samples for each period of heating. The plain carbon steels, particularly the low-carbon steel (En 32B) would be expected to behave similarly to bright mild steel, but it was found that the addition of gas to fuel oil generally increased the scaling loss for plain carbon steels, even at low excess air, in contrast to the effect on bright mild steel.

The Ni–Cr–Mo alloy steel was more resistant to scaling, as expected, than the plain carbon steels, but otherwise behaved similarly. The difference in the scaling loss of the alloy steel heated for 2 or 4 hr by fuel oil and town gas is generally less than that for plain carbon steels.

(E) Quantity of Adherent Scale *versus* Excess Air

Bright Mild Steel

Figure 9 shows the quantity of adherent scale plotted against excess air for bright mild steel for durations of ½, 2 and 4 hr of heating. The quantity of adherent scale when using fuel oil as the heating medium at low excess air is higher than that at 30 per cent excess air and may be attributed to the change in the nature of scale due to the formation of a low-melting-point iron oxide/sulphide eutectic at the metal-scale interface. Preece and Riley[21] and Griffiths[24, 25] who have qualitatively examined the adherence of scale to the metal, pointed out that the adherence of scale is due to intergranular penetration of the scale, and in the case of the molten type of scale formed in the sulphur-rich fuel-oil furnace atmosphere under conditions of low excess air this penetration is very severe. Furthermore,

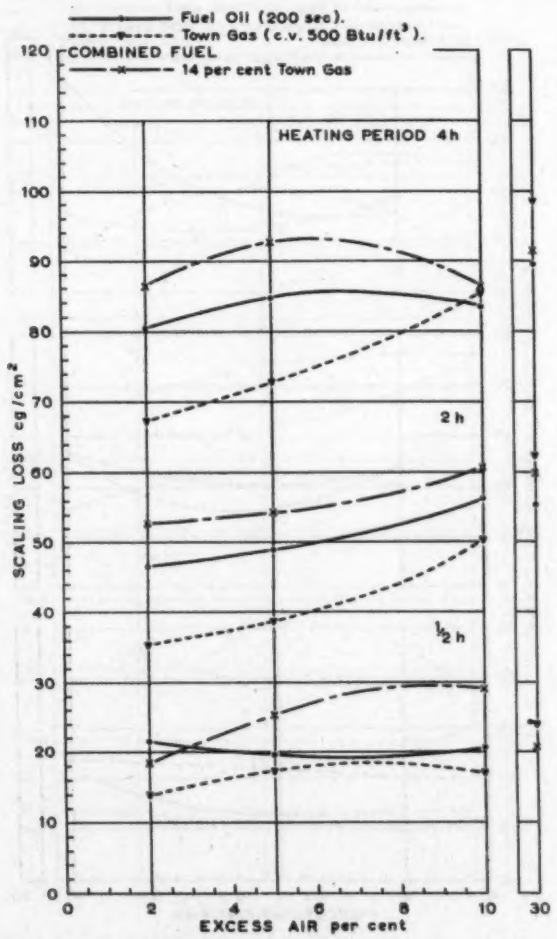


FIGURE 14.—*Scaling Loss* versus *Excess Air*, Ni-Cr-Mo, *Steel* (*B.S.* 970; *En* 26) *at* 1,200°C.

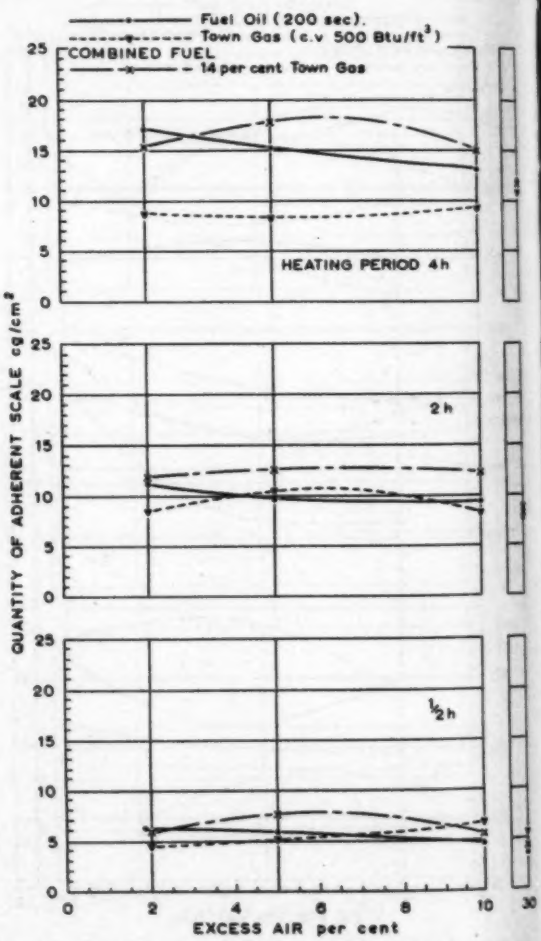


FIGURE 15.—*Quantity of Adherent Scale* versus *Excess Air*, Ni-Cr-Mo *Steel* (*B.S.* 970; *En* 26) *at* 1,200°C.

porous scale is regarded as being less adherent than the compact type of scale.

The heating of bright mild steel by town gas resulted in a much lower quantity of adherent scale than heating by oil, at low excess air, and this applies in the case of 4 hr heating even at 30 per cent excess air. The quantity of adherent scale for the combined fuels in comparison to that for oil depended on the conditions of heating, and no general conclusions can be drawn from the results. A noticeable reduction in the quantity of adherent scale is observed on addition of gas to fuel oil for 2 and 4 hr heating periods at 10 per cent excess air and also at 30 per cent excess air for the latter period of heating, the reduction being of the order of 30 to 40 per cent.

It has been pointed out that adherence of scale to the steel is due to the penetration of the scale into the metal, and evidence for this is given in sub-section (F).

Special Steels

Adherent scale *versus* excess air for the special steels is shown in Figures 11, 13 and 15. For the plain carbon steels heated by fuel oil, the quantity of adherent scale is high at about 10 per cent excess air, and as the excess air is either increased to 30 per cent or decreased to 5 per cent the quantity of adherent scale is reduced. Town gas heating showed a peak in the quantity of adherent scale at about 5 per cent excess air except for the ½ hr heating periods. This result does not agree with that obtained for bright mild steel. The addition of town gas to fuel oil either increases or decreases the quantity of adherent scale depending on the period of heating and excess air. For plain carbon steel (En 8) two conditions of heating, namely, 4 hr at 10 and 30 per cent excess air, show a marked decrease in the quantity of adherent scale on conversion from oil to combined fuels, the decrease being of the order of 60 per cent for the 10 per cent excess air condition.

The alloy steel results given in Figure 15 show that generally the variation of the quantity of adherent scale with excess air and type of fuel is less than that of plain carbon steels.

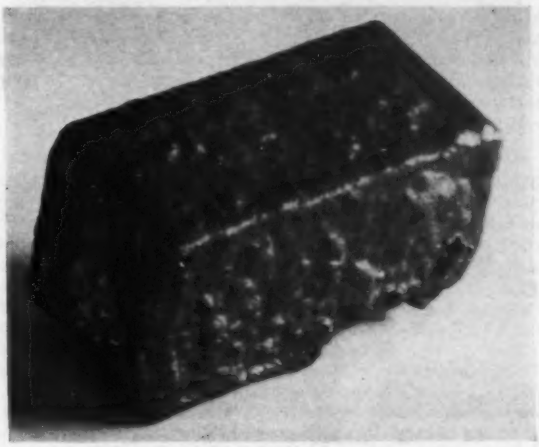
(F) Examination of Scale

Visual Examination

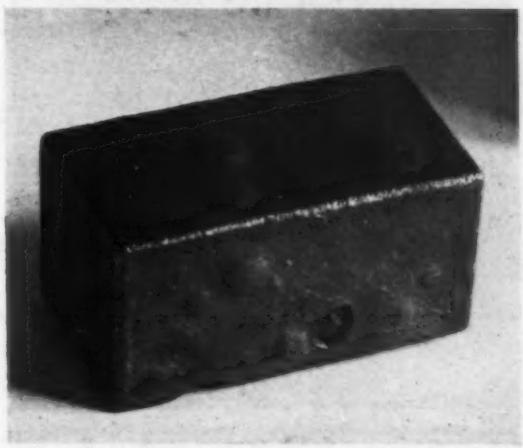
Figure 16 shows the type of scale formed on bright mild steel billets, of 2 in. × 2 in. × 4 in. size, used in the preliminary investigation and heated by fuel oil, combined fuel and town gas with 2 per cent excess air in the furnace atmosphere. It is apparent that the scale formed is of the molten type for fuel oil, highly crystalline for town gas, and of an intermediate type for combined fuel. Figures 17, 18 and 19 are of bright mild steels heated by the three fuels with 5 per cent excess air. Figure 17 shows one edge of the samples heated by the three fuels. It is seen that the scale formed on the sample heated by fuel oil is highly adherent in contrast to that heated by town gas. The nature of the scale-metal interface is shown by the photomicrographs in Figure 18. Figure 18 reveals the deep inter-granular penetration of the scale in steel heated by fuel oil and combined fuel respectively, and this accounts for the high adherence of the scale formed by these fuels. Very little inter granular penetration of the scale is noticeable for the steel heated by gas. The texture of the surface of the steel after the "hammer test" is shown in Figure 19. It will be noticed that the surface of the scale adhering to the steel heated by fuel oil is very rough in comparison to the steel heated by gas, undoubtedly due to the low-melting-point scale at the metal—scale interface, which was parted from the metal whilst in the molten or semi-molten condition.

Chemical Analysis

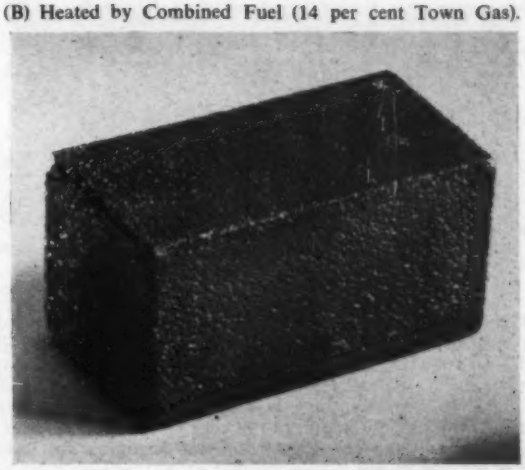
The results of the chemical analysis of the scale are presented in Table 12. The percentage of iron in the generally recognized



(A) Heated by Fuel Oil (200 sec).



(B) Heated by Combined Fuel (14 per cent Town Gas).



(C) Heated by Town Gas.

FIGURE 16.—*Scale Formation on Bright Mild Steel.* Conditions of Heating: Temperature of Steel, 1,200°C; Excess Air, 2 per cent; Period of Heating, 2 hr.

oxides of iron, ferrous oxide, ferroso-ferric oxide and ferric oxide are 77·7, 72·4 and 70 respectively. The values obtained by analysis in excess of 77·7 per cent may, therefore, be due to presence of unoxidized iron. The iron content of the scale calculated from

$$\frac{\text{Initial weight of sample} - \text{Weight of descaled sample}}{\text{Weight of scaled sample} - \text{Weight of descaled sample}}$$

was, however, 75 to 77 per cent, with the exception of three results for the ½ hr heating period. This suggests that the high iron content results of the analytical method may be due to iron pick-up from the steel during removal of the scale. On the basis that the scale formed in furnace atmospheres from fuel oil or gas is composed mainly of ferrous oxide and ferric oxide[18], the ferrous oxide and ferric oxide content was calculated from the ferrous and total iron results. The ratio of ferric to ferrous oxide was generally increased by about 50 per cent when the excess air was increased from 5 to 30 per cent for fuel oil and combined fuel, but not for town gas, where it was already at the higher level. This effect may be due to the change discussed previously in scale formation on steel heated by sulphur-rich fuels at low excess air.

TABLE 12.—*Analysis of Scale Formed on Bright Mild Steel at 1,200°C.*

Fuel	Excess Air (per cent)	Heating Period (hr)	Ferrous Iron by analysis (per cent)	Total Iron by analysis (per cent)	Total Iron* (per cent)	Ferrous Iron calculated as FeO (per cent)	Ferric Iron calculated as Fe_2O_3 (per cent)	† Sulphur cg/sqcm × 10^{-2} (by analysis)
1	2	3	4	5	6	7	8	9
Fuel Oil (200 sec)	5	½	59·0	77	79	76	25	12·60
		2	48·2	78	76	62	42	9·48
			49·0‡	77		63	40	
		4	56·7	79	76	73	32	16·10
	30	½	45·9	75	75	59	41	3·36
		2	46·7	76	76	60	44	4·74
		4	48·2	77	76	62	41	6·72
Combined Fuel: 14 per Cent Town Gas	5	½	59·0	79	77	76	28	14·22
		2	59·9	79	76	77	27	19·95
		4	—	—	—	—	—	—
	30	½	49·8	77	79	64	39	2·175
		2	48·2	78	77	62	42	2·570
		4	49·8	79	76	64	41	3·360
Town Gas	5	½	47·5	76	77	61	41	0·692
		2	53·6	80	76	69	37	1·422
		4	54·5	80	76	70	36	2·370
	30	½	48·2	76	79	62	40	0·613
			47·5‡	78		61	42	
		2	49·0	76	76	63	38	1·126
			50·5‡	77		65	38	
		4	51·3	76	76	66	35	1·560
			52·1‡	77		67	35	

* Calculated from (Initial weight of sample—Weight of descaled sample)/(Initial weight of sample—Weight of scaled sample).

† Sulphur in the scale remaining on the steel after removal of the bulk of the scale and in the steel surface, if any.

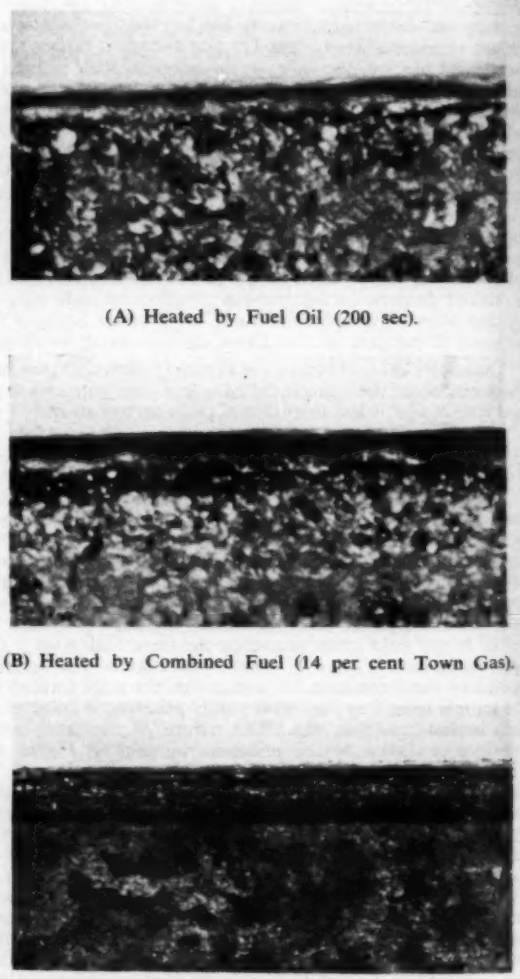
‡ Repeat analysis on a sample from the same scale.

The combined figures for sulphur in the steel surface and the thin layer of scale above it was high for both fuel-oil and combined fuel, particularly at 5 per cent excess air, in comparison to that for town gas. The sulphur in the bulk of the scale was 0·0296 cg/sq. cm for steel heated for 4 hr by fuel oil; this is only about 18 per cent of the total sulphur. The sulphur in the powdered scale was negligible for steel heated for 4 hr by gas.

It may be concluded that the sulphur is mainly concentrated in the surface layer of the steel and the layer of scale adjacent to it and that this increases with time of heating. Although the depth of sulphur penetration into the steel was not examined, it may be inferred from the above results that this would be high for steel heated by fuel oil and combined fuel at low excess air.

(G) DECARBURIZATION

In considering the results of the hardness surveys carried out on the special steels, it is convenient to consider them in the reverse order from that hitherto used. Figures 20 to 22, therefore, present the results in this order. When the first results became available, it was found that, particularly for the longer heating periods, the hardness of the specimen and, therefore, its carbon content appeared to have been affected throughout its thickness, originally ¼ in. but appreciably diminished by scale formation, with the result that the hardness curve never approaches the hardness value given by the control. In such cases, repeat runs were carried out on 1 in. thick



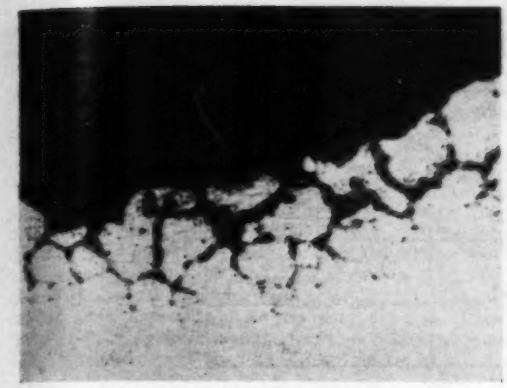
(A) Heated by Fuel Oil (200 sec).

(B) Heated by Combined Fuel (14 per cent Town Gas).

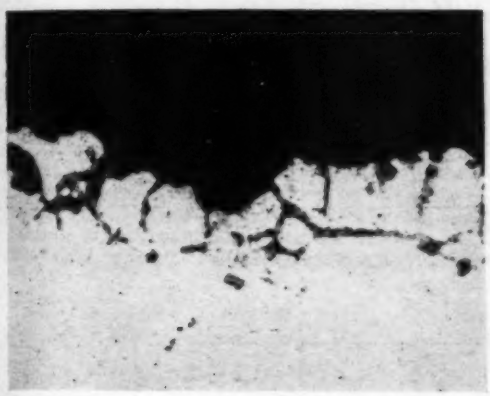
(C) Heated by Town Gas.

FIGURE 17.—*Scale Adherence on Bright Mild Steel.*

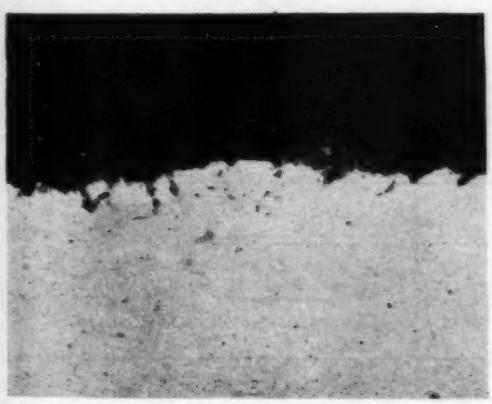
Conditions of Heating: Temperature of Steel, 1,200°C; Excess Air, 5 per cent; Period of Heating, 2 hr.



(A) Heated by Fuel Oil (200 sec).



(B) Heated by Combined Fuel (14 per cent Town Gas).



(C) Heated by Town Gas.

FIGURE 18.—*Photomicrographs showing Penetration of Scale into Bright Mild Steel.*
Conditions of Heating: Temperature of Steel, 1,200°C; Excess Air, 5 per cent; Period of Heating, 2 hr.

(A) Heated by Fuel Oil (200 sec).

(B) Heated by Combined Fuel (14 per cent Town Gas).

(C) Heated by Town Gas.

FIGURE 19.—*Texture of the Surface of Scaled Bright Mild Steel after "Hammer Test".*
Conditions of Heating: Temperature of Steel, 1,200°C; Excess Air, 5 per cent; Period of Heating, 2 hr.

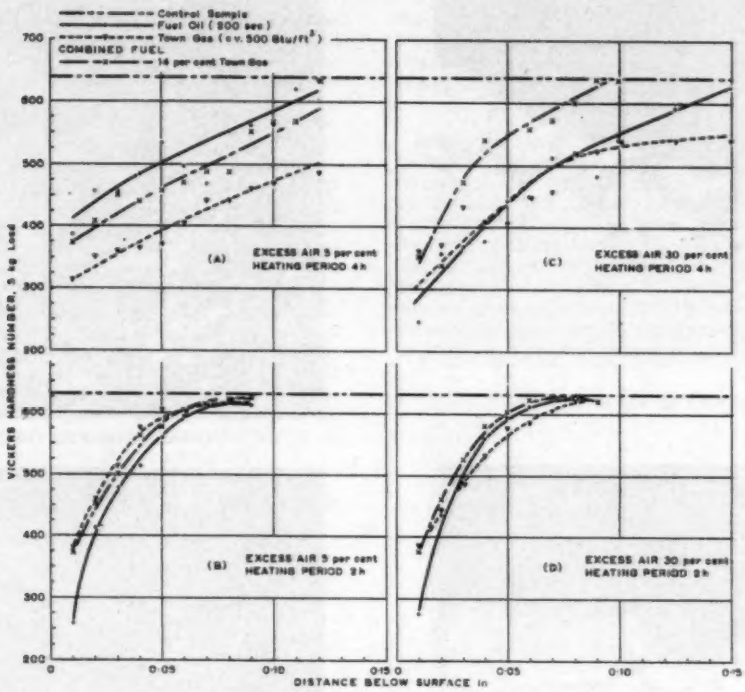

Control Sample
Fuel Oil (200 sec)
Town Gas (c.v. 500 Btu/ft³)
COMBINED FUEL
14 per cent Town Gas
VICKERS HARDNESS NUMBER, 5 kg Load
(A) EXCESS AIR 5 per cent HEATING PERIOD 4 h
(C) EXCESS AIR 30 per cent HEATING PERIOD 4 h
(B) EXCESS AIR 5 per cent HEATING PERIOD 2 h
(D) EXCESS AIR 30 per cent HEATING PERIOD 2 h
DISTANCE BELOW SURFACE in

FIGURE 20.—*Hardness Tests on* Ni-Cr-Mo *Steel* (*B.S.* 970; *En* 26).

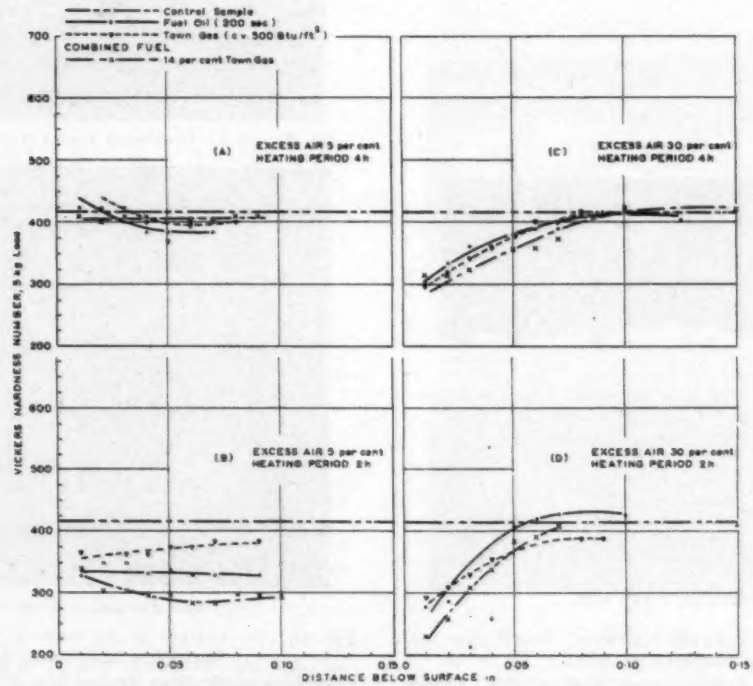

Control Sample
Fuel Oil (200 sec)
Town Gas (c.v. 500 Btu/ft³)
COMBINED FUEL
14 per cent Town Gas
VICKERS HARDNESS NUMBER, 5 kg Load
(A) EXCESS AIR 5 per cent HEATING PERIOD 4 h
(C) EXCESS AIR 30 per cent HEATING PERIOD 4 h
(B) EXCESS AIR 5 per cent HEATING PERIOD 2 h
(D) EXCESS AIR 30 per cent HEATING PERIOD 2 h
DISTANCE BELOW SURFACE in

FIGURE 21.—*Hardness Tests on Carbon Case Hardening Steel* (*B.S.* 970; *En* 32*B*)

samples from which ¼ in. thick specimens were cut after heating, and in most cases a more satisfactory curve obtained. Those new values have, therefore, been used in the preparation of Figures 20 to 22. It will be seen that the results are not as consistent as could have been wished, but, nevertheless, it is felt that some valid conclusions can be drawn.

Ni–Cr–Mo *Steel* (En 26) (Figure 20)

For this steel, heated for 2 hr, with the exception of the first 0·01 to 0·02 in. from the surface, there is little difference between the effect of the various flames; all decarburize. Close to the surface, oil produces more decarburization than town gas. When the heating is continued to 4 hr, a greater spread results. At high excess air, town gas is less decarburizing than oil; at low excess air the reverse is true. The mixed flame is roughly intermediate for low excess air, but less decarburizing than either fuel at high excess air.

Carbon Case Hardening Steel (En 32B) (Figure 21)

Three of the four sets of curves presented show little difference between the effect of the various flames: all decarburize. At 2 hr and 5 per cent excess air, fuel oil appears to decarburize more than gas, and the mixed flame most of all.

"35" *Carbon Steel* (En 8) (Figure 22)

The curves for 30 per cent excess air indicate decarburization with gas giving less than oil. The mixed flame is the most decarburizing at 2 hr, and is intermediate at 4 hr. At 5 per cent excess air the "35" carbon steel gave irregular results. The two sets of results (i.e., the original set obtained with ¼ in. thick samples and those that were repeated with 1 in. thick samples) are presented for 5 per cent excess air in Figures 22(A), (B) and 22(E), (F) respectively. It will be seen that, while the use of thicker samples resolved the failure to attain the control value before the centre is reached, other discrepancies appear. Perhaps this interpretation should be coloured by the fairly wide difference between the control values obtained in the two series, especially as similar differences between the hardness attained by the two sets of control samples did not appear in either of the other two steels. However, the fact remains that the relative positions of town gas and fuel-oil curves seem easily reversed, and, moreover, a swing from decarburization to carburization appears to take place.

It is of interest to compare these findings with those of Baukrowitz[8]. He reports consistent decarburization, with a reduction in carbon content of his surface layer of about 70 to 75 per cent with a 100 per cent fuel oil (40 sec), reducing by a smooth curve to some 45 to 50 per cent with 100 per cent coke oven gas. His results appear to have been more consistent than those now reported: this may well be due to the large number of determinations he was able to make. He used over 3,000 samples, and gives his scale-formation values as averages of 20 determinations. It must be noted, however, that he studied decarburization by chemical determination of the carbon content of a surface layer of steel 0·1 mm (0·004 in.) thick. It is possible that changes in carbon content so close to the surface will be considerable and lead to the appreciable advantage of gas over oil, which he reports. Some confirmation of this may possibly be found in Figure 20.

X CONCLUSIONS

While the primary object of the work was to investigate some of the merits claimed for the combined town gas/fuel oil flame, the results have also enabled some conclusions to be

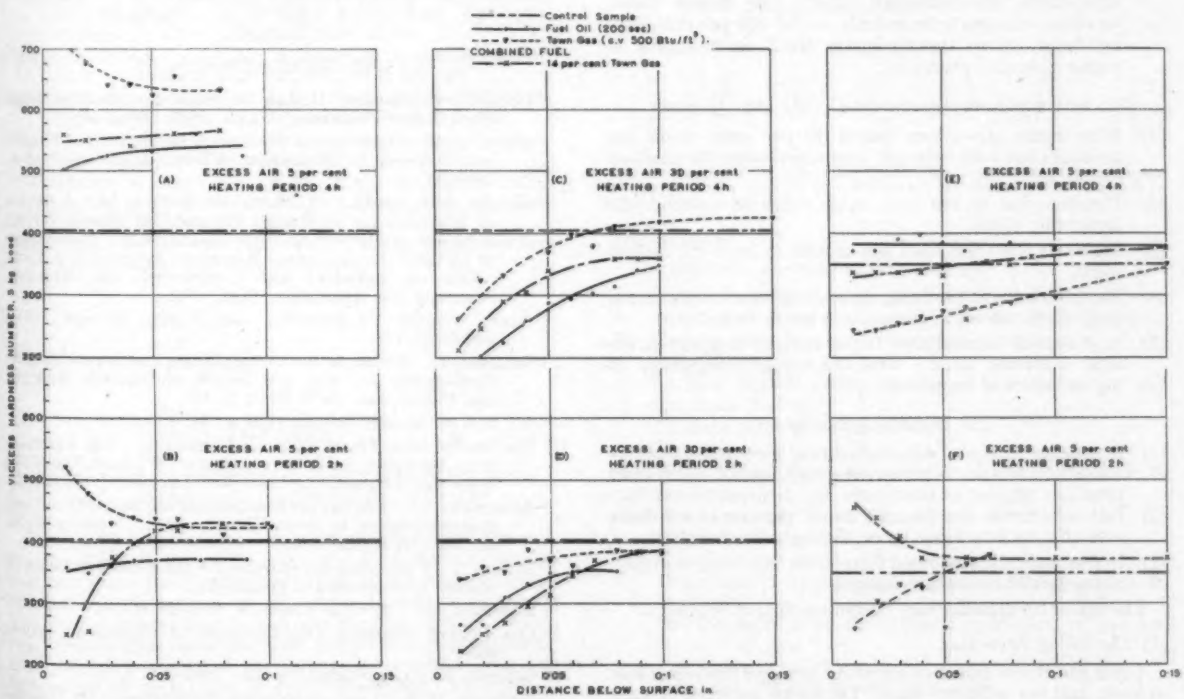

Control Sample
Fuel Oil (200 sec)
Town Gas (c.v. 500 Btu/ft³).
COMBINED FUEL
14 per cent Town Gas
VICKERS HARDNESS NUMBER, 5 kg Load
(A) EXCESS AIR 5 per cent HEATING PERIOD 4h
(C) EXCESS AIR 30 per cent HEATING PERIOD 4h
(E) EXCESS AIR 5 per cent HEATING PERIOD 4h
(B) EXCESS AIR 5 per cent HEATING PERIOD 2h
(D) EXCESS AIR 30 per cent HEATING PERIOD 2h
(F) EXCESS AIR 5 per cent HEATING PERIOD 2h
DISTANCE BELOW SURFACE in.

FIGURE 22.—*Hardness Tests on "35" Carbon Steel (B.S. 970; En 8).*

drawn concerning the relative merits of straightforward fuel oil and town gas for the heating of ferrous metals. It might well be that these conclusions will be felt to be more significant than those related to the combined flame.

The conclusions to be drawn may be summarized as follows:—

(A) Burner Performance

(1) With the 20 cu. ft combustion chamber maintained above about 1,000°C, the low-pressure air blast oil burner used was capable of burning 200 and 900 sec fuel oil with less than 2 per cent excess air.

(2) When the combustion-chamber conditions are less satisfactory, higher excess air is necessary, either to avoid smoke or to stabilize the flame. Under these circumstances, the addition of town gas to the fuel-oil flame can reduce the excess air and help to stabilize the flame.

(B) Scale Formation on Carbon Steels

(1) With excess air values below 10 per cent, town gas produces less scale than oil; at 30 per cent excess air this is reversed.

(2) Below excess air of 10 per cent, change in excess air has little effect on total scale formation when town gas is used; with fuel oil, the effect is considerable because of the presence of the iron oxide/sulphide eutectic.

(3) With bright mild steel, and at heating periods of 2 hr and above, 15 per cent of town gas in the flame gives about two-thirds of the advantage of town gas over fuel oil in respect of total scale formation. However, this benefit is, in any case, somewhat marginal, except possibly at 2 hr and 5 per cent excess air.

(4) At excess air values below 10 per cent, town gas produces significantly less adherent scale. The mixed flame, however, behaves substantially as the 100 per cent fuel-oil flame. Also, the advantage tends to disappear at higher values of excess air.

(C) Scale Formation on Ni–Cr–Mo Alloy Steel

(1) With excess air values below 10 per cent, town gas produces less scale than oil; above this value the position is reversed.

(2) Troubles due to the iron oxide/sulphide eutectic are apparently slight.

(3) Scale loss from this steel was as high as from the carbon steels.

(4) The mixed flame produces more scale than either of the single fuels when the excess air is below 10 per cent.

(5) At excess air values below 10 per cent, town gas gives the least adherent scale : this advantage disappears at higher values of excess air.

(D) Decarburization

(1) A general picture of decarburization is obtained from 11 out of the 14 sets of curves presented, and in seven cases town gas appears to have given less decarburization than fuel oil. Little can be said about the combined flame save that its behaviour is, on average, intermediate.

(2) In five cases, the combined flame is the least decarburizing, but generally by a small margin.

The above conclusions may be summarized as follows:—

(1) *The Use of Town Gas*

Town gas at low values of excess air can give low metal loss as scale, and low adherent scale. The excess air must be kept below 10 per cent to obtain this advantage.

(2) *The Use of Fuel Oil*

Difficulties will appear if the excess air is reduced, especially with heavy oils with their generally higher sulphur content.

Oil is always likely to produce more adherent scale than town gas in an efficient (i.e., minimum flue loss) furnace.

(3) *The Use of Combined Fuel*

There is little evidence to support the suggestion that disproportionate advantages can be attained by the addition of up to 15 per cent of town gas to an oil flame. It must be emphasized that this finding relates solely to its metallurgical effects and does not prejudice the other advantages outlined in Section IV(A) of the Paper.

Acknowledgments

The Authors wish to thank The Gas Council and the North Thames Gas Board for permission to prepare and present this Paper.

They are indebted to the Shell Petroleum Company, Limited, for considerable help and guidance in the techniques of fuel-oil utilization, to the British Iron and Steel Research Association, which not only provided the analysed samples of steels from its research stock, but also carried out all the examination of treated samples for decarburization, and gave invaluable advice on the metallurgical aspects of the whole project; and to Schieldrop and Company, Limited, for the loan of the combination gas/oil burner used.

Finally, the Authors desire to express their gratitude to many colleagues, both at Watson House and elsewhere, who have contributed in their various capacities, in particular Mr. P. F. Hayden and Mr. A. J. Hewitt on whom the burden of the practical work has largely fallen.

LITERATURE REFERENCES

[1] Eeles, C. C. Modern Heating Methods for the Steel Forge Plant. *Steel Processing*, March, 1949, **35**(3), 149.

[2] Clark, H. A. Furnaces and Mechanical Equipment for Forging and Forming of Metals and Alloys. *Industrial Heating*, 1952, **19**, 1.

[3] Slunder, C. J., Lyons, C. J., Gumz, W., Hall, A. M. A Review of Literature on the Results Obtained by Mixing Varying Amounts of Oil with Industrial Gases Before Combustion at Elevated Temperature. Report on Project 1A–6, Committee on Industrial and Commercial Gas Research, American Gas Association, Sept., 1953.

[4] Anon. Gas-Oil Co-operation. *Gas World*, 22 Sept., 1956, **144**(3762), 593.

[5] Schlosser, H. Probleme der Gemeinsamen und Abwechselnden Verfeuerung von Gas und Heizöl in Industrie Anlagen. *Gas Wärme*, Jan., 1958, No. 1, p. 51.

[6] B.C.U.R.A. Annual Report, 1959, p. 34.

[7] The International Flame Research Committee. The Radiation from Turbulent Jet Diffusion Flames of Liquid Fuel/Coke Oven Gas Mixtures. *J. Inst. Fuel*, Jan., 1956, **29**(180), 23.

[8] Baukrowitz, G. Einfluss der Ofenatmosphäre auf Abbrand und Rundentkohlung in einem Kleinstossofen. Werkstattstechnik, Jan., 1959, S.113–116.

[9] Jenkins, I. Controlled Atmosphere for the Heat Treatment of Metals. (Chapman and Hall, 1946.)

[10] Schroeder, W. *Arch. f.d. Eisenh. w.* 1932–33, **6**, 47.

[11] Gas Council Industrial Gas Development Committee Report 660/57.

[12] Schmidt, Th. *Gas Wärme*, 1st Jan., 1960, No. 1, 7.

[13] Mattocks, G. R. Coal Combustion Atmosphere in the Heating of Steel. Ph.D. Thesis, Univ. of Sheffield, 1952.

[14] Review of Oxidation and Scaling of Heated Solid Metals. (H.M.S.O., 1935.)

[15] Polushkin, E. P. Defects and Failure of Metals—Their Origin and Elimination. (Elsevier Publishing Co., 1956.)

[16] Jominy, W. E., and Murphy, D. W. Scaling of Steel at Forging Temperatures. *Trans. Amer. Soc. Steel Treating*, 1930, **18**, 19.

[17] Upthegrove, C., and Murphy, D. W. Scaling of Steel at Heat Treatment Temperature. *Trans. Amer. Soc. Steel Treating*, 1933, **21**, 73.

[18] Marson, C. B., and Cobb, J. B. The Influence of Atmosphere and Temperature upon the Scaling of Steel. *J.S.C.I.*, 1927, **46**, 61T.

[19] Blackburn, W. H., and Cobb, J. B. The Influence of Atmosphere on the Scaling of Mild Steel. *J.S.C.I.*, Nov. 1930, **49**, 455T.

[20] Preece, A. The Desirability of Removing Sulphur from Gaseous Fuels for Heating of Ferrous Metal. *J. Iron and Steel Inst.*, 1943, **147**(1), 43.

[21] Preece, A. and Riley, R. V. The Scaling Properties of Steels in Furnace Atmospheres at 1,150°C. *J. Iron and Steel Inst.*, 1944, **149**(1), 253.

[22] Murphy, D. W. Behaviour of Steel in Sulphur-containing Atmosphere at Forging Temperatures. *Trans. Amer. Soc. Steel Treating*, 1933, **21**, 510.

[23] Moreau, J., and Cagnet, M. The Scaling of Billets, Metal Treatment and Drop Forging, Sept., 1957, **24**(144), 407; Oct., 1957, **24**(145), 407; Nov., 1957, **24**(146).

[24] Griffiths, R. The Blistering of Iron Oxide Scales and the Conditions for the Formation of a Non-adherent Scale. *J. Iron and Steel Inst.*, 1934, **130**(11), 377.

[25] Griffiths, R. The Relationship between the Microstructure and the Adherence of Scale Deposits. *Carnegie Scholarship Memoirs* (Iron and Steel Inst.), 1937, **26**, 165.

[26] Guthrie, R. G. *Trans. Amer. Soc. Steel Treating*, 1929, **15**, 96.

[27] Simpson, P. B. Theoretical Considerations of the Oxidation and Decarburization of Steels during Heat Treatment. *Fuel Soc. J.*, Univ. of Sheffield, 1957, **8**, 32.

[28] Sachs, K., and Brown, J. R. A Theory of Decarburization by Scale. *J. Iron and Steel Inst.*, Oct., 1958, **190**, 169.

[29] Pilling, N. B., and Bedworth, R. E. The Oxidation of Metals at High Temperatures. *J. Inst. Metals*, 1923, **39**(1), 529.

[30] Pfeil, L. B. The Oxidation of Iron and Steel at High Temperatures. *J. Iron and Steel Inst.*, 1929, **119**(1), 501.

[31] Heindlhofer, K., and Larsen, B. M. Rates of Scale Formation on Iron and a Few of its Alloys. *Trans. Amer. Soc. Steel Treating*, 1933, **21**, 865.

[32] Sambrook, K. H. Fuel Oils: Their Efficient and Smokeless Combustion. *Petroleum*, Feb., 1954.

APPENDIX

CALCULATION OF FLUE GAS COMPOSITION FOR COMBINED TOWN GAS/FUEL OIL FLAMES

The composition of the furnace atmosphere and the percentage of excess air can be calculated for complete combustion of a single fuel from a knowledge of the composition of the fuel and the percentage of carbon dioxide or oxygen in the furnace atmosphere, which are easily measured. When two fuels are used simultaneously, the percentage of excess air and the composition of the furnace atmosphere will also depend on the proportion of each fuel burned. Therefore, if complete composition of the furnace atmosphere is to be calculated for combined fuels from the measurements of carbon dioxide or oxygen, and the composition of each fuel it is necessary to know the rates of delivery of each fuel to the burner.

The equations that correlate percentage of excess air and the ratio of town gas to fuel oil with each constituent of the furnace atmosphere are derived in this Appendix. The equations are for combined fuel, but they may be reduced to those that apply to a single fuel. Combustion equations for fuel oil are obtained by substituting zero for the gas rate in these equations; and those for gas are obtained by multiplying the numerator and denominator of the equations by the oil rate and substituting zero for the gas rate. The combustion charts, Figures 23 and 24, which are on a dry and a wet basis respectively, were prepared from the combustion equations for fuel oil, and for combined fuel and town gas for excess air up to 50 per cent and gas load of up to 25 per cent of the combined heat load. It was found that for these limits of excess air and proportion of each fuel, the values of oxygen in the furnace atmosphere do not alter appreciably from those calculated for fuel oil, and therefore, the fuel-oil curve for oxygen is also applicable to combined fuel. Because the oxygen content is independent of the proportion of each fuel within the limits stated above it is possible to determine the ratio of gas to oil from the measurements of carbon dioxide and oxygen content only of the furnace atmosphere. A comparison of ratios of gas to oil calculated by this means and that obtained by measurement of fuel rates is given in Table 13.

TABLE 13.—*Comparison of Measured and Calculated G/L ratio (G/L = cu. ft. of town gas/lb. of fuel oil (200 sec.)).*

Oil Rate (gal/hr)	Gas Rate (cu. ft/hr)	Flue Gas Analysis (on a dry basis)		Excess Air from Equation 3a*	Calculated G/L from Equation 1a	Measured G/L (from fuel rates) (cu ft/lb)
		CO_2 (per cent)	O_2 (per cent)			
1	2	3	4	5	6	7
2·10	98	15·2	0·4	1·8	5·3	4·9
3·26	189	11·3	5·6	34·2	6·4	6·1
3·38	212	15·0	0·5	2·3	7·5	6·6
2·43	235	14·8	0·4	1·8	11·9	10·2
2·48	300	14·8	0·3	1·4	13·5	12·8

* The variation of G/L in the range 1 to 12 has negligible effect in the calculation of excess air from equation 3a, and G/L = 6 has been used for calculation of column 5.

Nomenclature

The following nomenclature is used:—

- *A* Air for theoretical combustion of oil (cu. ft/lb of oil).
- *a* Air for theoretical combustion of gas (cu. ft/cu. ft of gas).
- *B* Carbon dioxide from theoretical combustion of oil (cu. ft/lb of oil).
- *b* Carbon dioxide from theoretical combustion of gas (cu. ft/cu. ft of gas).
- *C* Calorific value of oil (B.t.u./lb).
- *c* Calorific value of gas (B.t.u./cu. ft).
- *D* Water vapour from theoretical combustion of oil (cu. ft/lb of oil).
- *d* Water vapour from theoretical combustion of gas (cu. ft/cu. ft of gas).
- *E* Excess air (per cent).
- *F* Dry products from theoretical combustion of oil (cu. ft/lb of oil).
- *f* Dry products from theoretical combustion of gas (cu. ft/cu. ft. of gas).
- *G* Gas rate (cu. ft/hr).
- *H* Gas load (per cent of total heat load).
- *K* Factor for conversion of composition of furnace atmosphere from a dry to a wet basis.

L Oil rate (lb/hr).
M Sulphur in oil (lb/lb of oil).
m Sulphur in gas (lb/cu. ft of gas).
w Water vapour in furnace atmosphere (per cent by volume).
x Carbon dioxide in furnace atmosphere (per cent by volume).
y Oxygen in furnace atmosphere (per cent by volume).
z Sulphur dioxide in furnace atmosphere (per cent by volume).

Assumptions

The following assumptions are made in deriving the combustion equations:—

(*a*) The combustion of fuel is complete that is all the carbon and hydrogen in the fuel appear as carbon dioxide and water vapour in the products of combustion.
(*b*) Sulphur present in the fuel burns to sulphur dioxide.
(*c*) Water vapour in the air for combustion is negligible.

General Derivation of Combustion Equations

For simultaneous combustion of L lb of oil and G cu. ft of gas

Volume of theoretical air $= AL + aG$ cu. ft.

Volume of dry products from theoretical combustion $= FL + fG$ cu. ft.

Volume of excess air $= (AL + aG)\ E/100$ cu. ft.

Volume of oxygen in furnace atmosphere $= 0{\cdot}21(AL + aG)\ E/100$ cu. ft.

Volume of carbon dioxide in furnace atmosphere $= BL + bG$ cu. ft.

Volume of water vapour in furnace atmosphere $= DL + dG$ cu. ft.

Volume of sulphur dioxide in furnace atmosphere $= 2(ML + mG)\ 379/64$ cu. ft. $= 11{\cdot}85(ML + mG)$ cu. ft.

Therefore, percentage of carbon dioxide in furnace atmosphere (on a dry basis),

$$x = \frac{(BL + bG)}{FL + fG + (AL + aG)\ E/100}$$

$$= \frac{100B + 100bG/L}{F + fG/L + 0{\cdot}01(A + aG/L)\ E} \quad . \quad . \quad (1)$$

or

$$E = \frac{100B - Fx + (100b - fx)\ G/L}{0{\cdot}01Ax + 0{\cdot}01axG/L} \quad . \quad . \quad (2)$$

Percentage of oxygen in furnace atmosphere (on a dry basis)

$$y = \frac{0{\cdot}21(AL + aG)\ E/100}{FL + fG + (AL + aG)\ E/100} \times 100$$

$$= \frac{0{\cdot}21(A + aG/L)\ E}{F + fG/L + 0{\cdot}01(A + aG/L)\ E} \quad . \quad . \quad . \quad (3)$$

Percentage of water in furnace atmosphere,

$$w = \frac{(DL + aG)\ 100}{DL + dG + FL + fG + (AL + aG)\ E/100}$$

$$= \frac{(D + dG/L)\ 100}{F + D + (f + d)\ G/L + 0{\cdot}01(A + aG/L)\ E} \quad (4)$$

Percentage of sulphur dioxide in furnace atmosphere (on a dry basis),

$$z = \frac{11{\cdot}85(ML + mG)\ 100}{FL + fG + (AL + aG)\ E/100}$$

$$= \frac{1185(M + mG)}{F + fG/L + 0{\cdot}01(A + aG/L)\ E} \quad . \quad . \quad (5)$$

Factor for conversion of composition of furnace atmosphere from a dry to a wet basis,

$$K = \frac{\textit{Volume of dry flue gas}}{\textit{Volume of wet flue gas}}$$

$$= \frac{FL + fG + 0{\cdot}01(AL + aG)\ E}{FL + fG + 0{\cdot}01\ (AL + aG)\ E + DL + dG}$$

$$= \frac{F + fG/L + 0{\cdot}01(A + aG/L)\ E}{F + D + (f + d)\ G/L + 0{\cdot}01(A + aG/L)\ E} \quad (6)$$

Gas load as a percentage of total heat load,

$$H = \frac{cG}{cG + CL} \times 100 \quad . \quad . \quad . \quad . \quad (7)$$

Equations for Use with G4 Town Gas and 200 sec Fuel Oil

Stoichiometric combustion calculations for fuel oil (200 sec) and G4 town gas of typical compositions, given in Tables 1 and 3 respectively, resulted in the following values for the constants in the general equations:—

$A = 183$; $B = 27{\cdot}41$; $D = 21{\cdot}9$; and $F = 172{\cdot}4$
$a = 4{\cdot}26$; $b = 0{\cdot}471$; $d = 1{\cdot}053$; and $f = 3{\cdot}91$

and from the analysis of the fuels $M = 0{\cdot}03$ and $m = 0{\cdot}32 \times 10^{-4}$.

The calorific values of town gas and fuel oil (200 sec) are $c = 500$, and $C = 18{,}340$ respectively.

The equations given below for combined fuel oil (200 sec) and town gas are obtained by substituting the above values in equations 1 to 7.

$$x = \frac{2741 + 47{\cdot}1G/L}{172{\cdot}4 + 3{\cdot}91G/L + (1{\cdot}83 + 0{\cdot}0426G/L)\ E} \quad (1a)$$

$$E = \frac{2741 - 172{\cdot}4x + (47{\cdot}1 - 3{\cdot}9x)\ G/L}{1{\cdot}83x + 0{\cdot}0426xG/L} \quad (2a)$$

$$y = \frac{(38{\cdot}4 + 0{\cdot}894G/L)\ E}{172{\cdot}4 + 3{\cdot}91G/L + (1{\cdot}83 + 0{\cdot}0426G/L)\ E} \quad (3a)$$

$$w = \frac{2190 + 105{\cdot}3G/L}{194{\cdot}3 + 4{\cdot}96G/L + (1{\cdot}83 + 0{\cdot}0426G/L)\ E} \quad (4a)$$

$$z = \frac{35{\cdot}55 + 0{\cdot}0379G/L}{172{\cdot}4 + 3{\cdot}91G/L + (1{\cdot}83 + 0{\cdot}0426G/L)\ E} \quad (5a)$$

$$K = \frac{172{\cdot}4 + 3{\cdot}91G/L + (1{\cdot}83 + 0{\cdot}0426G/L)\ E}{194{\cdot}3 + 4{\cdot}96G/L + (1{\cdot}83 + 0{\cdot}0426G/L)\ E} \quad (6a)$$

$$H = \frac{500G/L}{18{,}340 + 500G/L} \quad . \quad . \quad . \quad . \quad (7a)$$

Combustion Charts

The combustion charts (Figures 23 and 24) were prepared to facilitate the application of the above equations. These charts show lines for oil so that comparison can be made of the composition of furnace atmospheres from the combustion of oil and combined gas/oil fuel.

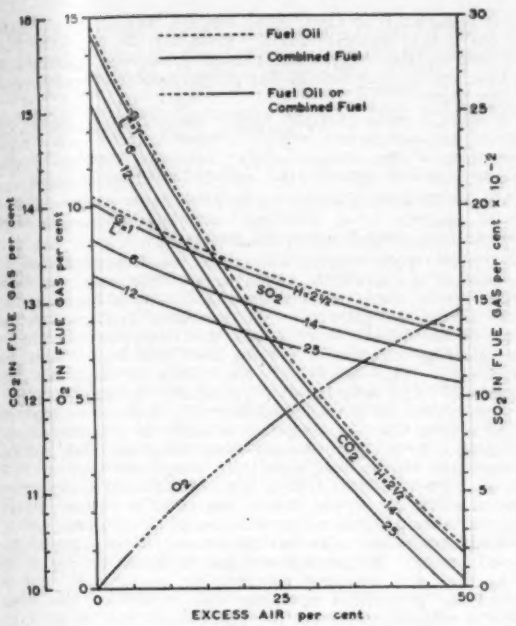


FIGURE 23.—*Combustion Chart (On a Dry Basis).*
(Fuel Oil, 200 sec. Town Gas, 500 B.t.u./cu. ft.)

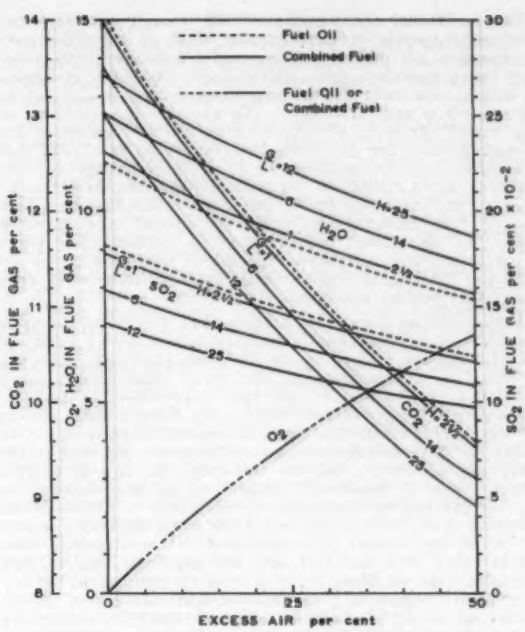


FIGURE 24.—*Combustion Chart (On a Wet Basis).*
(Fuel Oil, 200 sec. Town Gas, 500 B.t.u./cu. ft.)

PRESENTATION, DISCUSSION AND REPLY

Presentation

Mr. E. A. K. Patrick presented this paper and summarized its contents. He said, also, that since the paper was written some further runs had been made to discover whether the use of a heavier oil would show significantly different results. For this purpose, 900 sec. oil was used in place of the 200 sec. oil used for most of the work reported in the paper. It was found that the total scale formed at 30 per cent excess air was less than that given by the lighter oil, but that at 10 per cent excess air the total scale formed was greater than that given by the lighter oil; this was to be expected from the use of an oil with rather higher sulphur content. On the other hand, with both 10 and 30 per cent excess air, the weight of the adherent scale formed was identical with that given by the lighter oil.

It was, continued Mr. Patrick, presumably a reasonable expectation that progress in furnace design and management would tend to reduce the excess air in many furnaces to below 10 per cent. If this were done, a gas-fired furnace would have substantial attractions over those fired by oil, and this was the principal conclusion from the work described.

Discussion

Dr. R. S. Edwards (Leeds; Chairman, North Eastern Gas Board):—I am pleased to open the discussion of a paper concerned with the utilization of gas, because this seems to me to be the matter that is of the most immediate and practical importance so far as the gas industry is concerned.

After all, present methods of production of gas scientifically are reasonably efficient. It would be hard to claim that all phases of use of gas, particularly in the industrial field, are equally efficient from a scientific point of view. Where there is possible scope for efficiency, then the rewards in the context of high-priced fuel are obviously very substantial. In the present state of the gas industry, this aspect is one of vital significance.

This paper is a record of a painstaking examination of one particular aspect and one that, superficially, is very attractive. Can a cheap liquid fuel be mixed with a substantially dearer gaseous fuel and give a combined fuel that will do something which neither will do on its own, and at an attractive price? The first lesson to be learnt from the paper is that the possible application of dual-fuel flames cannot be defined by simple considerations of general principles. The paper contains, in its early stages, a particularly useful and interesting résumé of the thoughts on this subject which have been put forward from time to time. It is clear from this study that each application has to be considered on its merits, as the authors have been careful to say. Even although the principal conclusion of the paper is substanially negative with regard to the special problem of scale, it has brought out or, perhaps, re-emphasized the importance of excess air, which, incidentally, means the importance of a renewed study of furnace design.

Too much of the industry's approach to the utilization of gas has been based on purely empirical considerations. One should not, of course, deny or even quibble at the great success that has been achieved from the commonsense application of this approach, and I would make a plea for an increase in the volume of the industry's research effort applied to investigational work of the type now under consideration.

This paper should, therefore, be considered in the nature of a pioneer effort of controlled laboratory inquiry into what is a great need of the industry at the present time. In other words, the sort of work that is documented and presented in this paper could usefully provide information upon which furnace builders and industrial engineers could achieve rapid increases in the efficiency of utilization of gas, and, therefore, demonstrate the overall attractiveness of gas as a heating medium in industry.

I hope this will not be the last of such papers.

Mr. L. Walker (Birmingham):—Mr. Patrick and Mr. Patel have given details of experimental work in connexion with combination gas/oil burners as used for heating steel billets. They have provided some useful facts regarding the degree of scaling, not only for the combined fuels but also for gas and oil when used separately. To criticize the work in any way would appear to be unjust, as the authors present a very favourable case for gas firing in forge furnaces. They have established that the addition of a small percentage of town gas to oil gives conditions approximately intermediate between those of the individual fuels. More important than this, however, is that industrial gas engineers should take particular notice that the results indicate that, for conditions of excess air of 10 per cent and below, the use of town gas on its own gives less total scale and less adherent scale than when oil is used under similar conditions.

Table 9 shows that under conditions of 5 per cent excess air and for ½ hr heating period, the scale loss was 28·1 cg/sq. cm for oil firing and 17·8 cg/sq. cm for town gas firing. This loss, expressed as a percentage of the initial billet weight, which was 250 g, is 13·8 and 8·7 per cent respectively. Thus, there is a saving of 5·1 per cent of metal if gas firing is used. Taking the cost per cwt as 50*s*. this difference in percentage loss would mean a saving of approximately 2*s*. 6*d*./cwt. This figure is probably on the low side since the cost of the raw material only is considered, without taking into account the cost of purchasing the material, delivering it to the works, accepting it into stores, booking it out and transferring it from the stores, and cutting off to length, *etc*. On the other hand, one is aware that the fuel cost for gas firing can be more expensive than oil firing. For a basis of comparison today, I have taken a figure of 2 therms/cwt, and with gas at 1*s*. 4*d*./therm and oil at 7*d*./therm it is evident that, for similar conditions of efficiency, *etc*, there is a difference of 1*s*. 6*d*./cwt in favour of oil firing, but, considering the overall position, there is a difference of 2*s*. 6*d*. less 1*s*. 6*d*., i.e., 1*s*./cwt, in favour of town gas. I appreciate that not all gas is sold at 1*s*. 4*d*./therm, but these figures surely suggest that no industrial gas engineer should have any difficulty in obtaining all the billet-heating load for town gas.

One should, therefore, at this stage, ask oneself why this is not done, and why are industrial gas engineers endeavouring to obtain only 5, 10, or perhaps 15 per cent of the fuel input to oil-fired furnaces because of the belief that for various reasons they can not obtain the total load. We shall be justified in looking closer into the results presented by Mr. Patrick and Mr. Patel in an effort to find the answer to this question.

Whilst I have said that to criticize the work of the authors in any way would be unjust, one or two aspects of the tests warrant closer examination. Firstly, I submit that the furnace as illustrated in Figure 1 is typical of many "boxes of bricks" we used to find a few years ago, and I am sure that most industrial gas engineers have progressed to more efficient designs than that shown. In my experience, it is usual in practice to operate forge furnaces under pressurized conditions and one commonly sees furnaces in use with flame showing at the discharge door; in particular, slot-type furnaces are highly pressurized with very little, if any, excess air. Therefore, I am sure that the values for excess air taken in the experiment are unrealistic; even more unrealistic are the times allowed for soaking. The minimum time given in Table 9 was for a heating period of ½ hr, and I am sure that the size of billet used would reach maximum temperature within a few minutes. I suggest that this extensive time of immersion would particularly affect the type of scaling produced, and that these factors should be re-examined. If further work is to be done, I suggest also that the tests be extended to include billets raised to a temperature of 1,250°C, and that a reasonable temperature head in the furnace be adopted.

In the West Midlands, consumers have, from time to time, said that the type of scale produced in gas-fired forge furnaces is very detrimental to tools, dies, *etc*., which have to be used in subsequent operations. Where a forging is subsequently to be machined, town gas is often ruled out. In endeavours to increase the forging load, the West Midlands Gas Board has been concentrating on furnace design, with particular emphasis on temperature distribution and control to avoid overheating. This point is particularly more important today as increasing use is being made of alloy steels, and any loss due to overheating has a high financial value. Yesterday, we heated a ¼ in. specimen to these temperatures under pressurized furnace conditions, and we had nothing like the percentage of scale quoted in the paper.

In short, I plead that any further tests shall be carried out with all relevant factors similar to those found in actual practice; then, if the authors obtain the same conclusions, the industry can look again at the potential billet-heating load.

Mr. W. H. Tarn (Cardiff):—I find this paper a very awkward one to comment upon, although I certainly applaud the work that has been carried out by the authors.

I support from practical experience the comments made by the authors in Section IV of the paper. Interest in the Wales Area so far as the combined burner is concerned has been twofold. In the first place, we were anxious to find an outlet for some of the Board's surplus gas, and were not able to get into the high-temperature forging field that Mr. Walker has mentioned. The whole of the South Wales area was "combed"—and when I say "combed" I mean combed—to find a user for a combined burner. After some time, we found a firm that was prepared to allow us to carry out experiments. It was a pin-head furnace using oil. We installed a combined burner and ultimately ended up with a 50:50 gas/oil mixture. The firm concerned was not interested in thermal efficiency; it was mainly interested in output. Therefore, we were anxious to know if we could compete with an oil-fired installation. Our results proved that we got an improved product; the scaling was not so hard, the life of the refractories was extended anything up to ten-fold, and we trebled the production rate that was required. This might sound a splendid story, but the unfortunate part about it was that the firm concerned decided to leave the Wales Area, and we were unable to continue our experiments.

I look upon all this work purely as an interim stage. Members have heard about gas being transported from London to Birmingham, and from Birmingham to London, and so on. Sometime, somebody has to consider the overall base-load plant, and, so far as I am concerned, I think that the only way we can hope to obtain a base load on all major gas-distribution plant is by industrial application. I am convinced that this type of work has to be continued. I rather regret that the authors have kept this work primarily to furnace work. There are plenty of applications where oil is used and where it would be of great advantage to install a combined burner. On this score, although the outcome of the paper is, perhaps, somewhat negative, I think it is necessary as an interim stage to the industry's ultimate aim. One should bear in mind that the design of all industrial equipment is becoming far more specialized at the present time, and firms cannot be expected to convert everything over to 100 per cent gas-fired installations. There is, however, one way of obtaining a portion of the load, and this by the application of the type of burner described. I hope the work will be continued in the broadest way possible and not kept to furnace work or any other specific application.

Mr. P. J. Foster (University of Sheffield):—One point that has been mentioned is that the use of a small amount of gas leads to a reduction in the amount of excess air. This has been confirmed by the work completed by Mr. Allen at the University of Sheffield, under the sponsorship of the Gas Council Research Committee. Mr. Allen found that, by burning a gas/oil flame, he could reduce excess air from between 20 to 30 per cent to about 5 per cent and still retain a stable flame.

The purpose of the work was not really related to forging furnaces, but was part of some work directed more to controlling emissivity and length of flames. The gas was used more to control the emissivity. Using four slot burners situated around a pressure-jet gas/oil burner, it was found that introducing gas around this oil flame increased its emissivity. A maximum increase in peak emissivity from 0·5 to 0·7 was obtained using 22 per cent gas.

Mr. Tarn has mentioned that there is less refractory trouble with a gas/oil flame, and in the paper reference is made to the fact that the use of a gas/oil flame will give less refractory

trouble due to there being less radiation or unburnt fuel. This would suggest that if a small amount of gas be used there should be more refractory trouble if in fact the trouble is due to radiation, and possibly less if it is due to unburnt fuel. In the case referred to, 50:50 gas/oil was being used and the flame would be more or less a gas flame.

Dr. A. E. Haffner (Southampton):—My contribution represents a small side stream that deviates a little from the specific object of studying dual-fuel burners applied to the heating of ferrous metals.

There is, perhaps unsuspected by the authors, an interest in dual-fuel burners in cyclic catalytic reforming plant making town gas from petroleum products. Some of these plants are normally based on refinery gas, but in some other countries on natural gas. Should there be a cessation of supplies of these gaseous feedstocks, it is necessary to take emergency measures to supply a liquid feedstock both during the blow phase and the gas-making phase. These gas-making units are large, and a delay in changing over from gaseous to liquid feedstock would be reduced if a dual-fuel burner were adopted. Some American plants have this facility, but it has not yet appeared on British plants. In certain circumstances, even combination gas/liquid burners that would allow a liquid and a gas to be burnt separately or simultaneously would be of interest in such plants.

The authors may like to know that the paper has attracted the attention of a rather wider audience whose real interest is in gas-production plant design and operation.

Mr. R. F. Hayman (London):—It is not always possible to lead research work in the way originally planned, but what matters is to get a result. We can see in this work encouragement for industrial gas engineers, and we cannot repeat too often that it offers a challenge to designers in that, of all the fuels available for industrial heating, gas is the one that lends itself most readily to the rigid control of excess air.

There has been much discussion on finding the perfect mixture of gas and oil, which began some years ago in the work of the International Flame Research Foundation at IJmuiden where one objective was to discover the fundamental mechanism for making the best use, on a large scale, of the available coke oven gas by mixing it with the minimum amount of oil so that full use could be made of the high emissivity of the resulting flame in promoting rapid rates of heat transfer.

Work at IJmuiden was inevitably associated with, and influenced by, large-scale use of oil in steel works and, for instance, in the glass industry. There remained for the gas industry the need to examine a combination of oil and gas in the many thousands of relatively small-scale billet- and process-heating furnaces in the country. I am here largely concerned with the more exacting processes, and not just crude metal heating.

In such equipment, incidentally, the use of high emissivity is not by any means the best way to produce rapid heating. There were, and probably still are, varying schools of thought on this work, one being that the development of the combination burner could make it easier for customers to change over from gas to oil. I believe that if the customer wishes to make such a change he will do so as soon as he can, regardless of the existing equipment, and I see opportunities in the authors' work to discover whether a combination of oil and gas is likely to be a better fuel technically than gas alone.

The fact that the authors suggest it is not, in itself a most important discovery, and, in pinpointing their conclusions, one must take greater heart and go out and sell gas for those processes now inadequately served by oil.

Written Reply

The Authors, in reply, wrote:—The authors are grateful to Dr. Edwards for having underlined the need for investigations of the type described in this paper, and for having set them in perspective with work in other fields.

Mr. Walker has presented an estimate in financial terms that is based on the percentage loss in weight of our samples. The authors do not feel that this is correct, as their samples were not intended as workpieces. In order to obtain accurate figures for change in weight, they were obliged to use test pieces with a high surface area to volume ratio, and therefore decided on pieces of steel ¼ in. thick. They were careful to express their results in terms of change in weight per unit area, and intended that their samples should represent portions of the surface of much larger billets. This fact explains also their heating times, which were made sufficiently long to be representative of practice in making larger forgings than Mr. Walker has in mind; there is the further point that the authors wanted to have amounts of scale sufficiently large to be measurable, and to permit comparisons.

With reference to Mr. Walker's point concerning furnace pressures, the authors' furnace was operated with a positive pressure at its upper levels. The positive furnace pressure referred to by Mr. Walker is readily attained in slot forge furnaces, but would be much more difficult to attain in larger furnaces with a considerable working height. While in the authors' furnace the pressure at hearth level may have been slightly negative, the in-leakage of air at the door did not penetrate far towards that area of the hearth that was used for samples. The samples were mounted on refractory platforms 1 in. high (see Figure 5), and gas analysis carried out 1½ in. above the hearth in the plane B—B (Figure 1) indicated no significant difference in the atmosphere here from that in the remainder of the furnace. A further point is that each test involved two runs, and the set of duplicate samples used in each run were never both in the region of sample point 9, so that significant in-leakage at the door (which fitted well) would have shown up as a marked difference between the scaling of the set of duplicate samples; this was not, in fact, found.

The design of the furnace, also commented on by Mr. Walker, was largely dictated by the requirements of the burner, and there was no intention to reproduce a forging furnace; moreover, the furnace was considerably more gas-tight than most, as is evidenced by the authors' ability to get down to 2 per cent excess air as determined by flue gas analyses.

The authors were interested to hear of Mr. Tarn's experiences in finding a suitable outlet for this type of burner, and particularly to learn that an appreciable improvement in furnace life can be obtained in practice. It was indeed a pity that the firm concerned moved away, as "nothing succeeds like success", and one successful installation can lead to many others.

Mr. Allen has tackled a different aspect of the combined flame, and the authors hope that out of a fundamental study of this type of flame some radical improvement may arise.

Dr. Haffner has indicated an interesting possibility in gas-making practice for which the combination burner seems very suitable, and the authors would be interested to learn whether this use is successfully developed.

Mr. Hayman's contribution is understood as placing the authors' work in the wider context both of work at IJmuiden and in methods of applying fuels and combustion systems to heating problems. Like Mr. Hayman, the authors regard their conclusions concerning the merits of the combined flame as truly positive and offering further scope for the direct sale of town gas.

REPORT ON THE GAS COUNCIL RESEARCH SCHOLARSHIPS: 1960

RESEARCH COMMUNICATION GC73

TABLE OF CONTENTS

		PAGE
I	Introduction	184
II	Scholars and their Studies	184
(1)	Mr. P. Hawtin	184
(2)	Mr. J. N. Sherwood	184
(3)	Mr. A. Richmond	185
(4)	Mr. K. J. Reid	185
(5)	Mr. D. Wilson	186

I INTRODUCTION

The five scholars awarded scholarships in 1957 have now completed their tenure of the scholarships. They have submitted final reports, the full texts of which are available at the offices of The Gas Council. A short account of the work of each scholar is given below.

Anyone who would like more detailed information on any of this work is invited to write to The Gas Council, at Murdoch House, 1, Grosvenor Place, London, S.W.1.

II SCHOLARS AND THEIR STUDIES

(1) Mr. P. Hawtin

Studying in the University of London, under Professor M. B. Donald, this scholar has carried out work on the gaseous oxidation of *p*-xylene.

The gaseous oxidation of *p*-xylene at temperatures from 460° to 512°C was studied in a static system using " Pyrex " glass reaction vessels of about 300 ml capacity. Mixtures of between 10 and 1 mole of oxygen/mole of *p*-xylene, at total initial pressures from 50 to 560 mm were studied. Published work on the oxidation of *p*-xylene is very limited, and no analytical results have previously been reported.

The object of the present work was to determine the kinetics of the *p*-xylene oxidation, as measured by the pressure change, and to relate these data to the chemical changes occurring in the reaction vessel. The results obtained have been used to formulate a mechanism for the reaction.

The rate of reaction accelerated exponentially to a steady rate and then fell again, giving rise to a sigmoidal pressure—time curve. Over the range of mixture compositions and temperatures investigated, the maximum rate of reaction was found to obey the relationship :

$$d(\Delta P)/dt = kP^n$$

where P is the total initial pressure, or the partial pressure of oxygen, and k and n are constants at constant mixture composition. The reaction rate was less sensitive to *p*-xylene partial pressure, but, at mixture compositions in the middle of the concentration range studied (2·5 to 7·5 moles of oxygen/mole of *p*-xylene), n was approx. 1. For a mixture of 2·5 moles of oxygen/mole of *p*-xylene, the rate data were represented by

$$d(\Delta P)/dt = 10^{8.47} p^{2.68} \exp(-48{,}000/RT) \text{ mm/min.}$$

where P refers to the total pressure in millimetres.

The pressure rise has been related to the chemical changes occurring in the reaction vessel, for a mixture of 2·5 mole oxygen/mole of *p*-xylene, at the two extremes of the temperature range studied. Pressure balances drawn up for the contents of the vessel were sensibly complete at all stages of the reaction, but element deficiencies in the element balances indicated the formation of a solid deposit, and this was observed as a blackish-brown material on the cooler parts of the reaction system.

The reaction was demonstrated to proceed by a free radical degenerate branching chain mechanism, and formaldehyde was proved to be the intermediate responsible for this branching. The free radical chains are ended by radical de-activation at the walls of the reaction vessel.

(2) Mr. J. N. Sherwood

This scholar, working in the University of Glasgow, under Professor J. Monteath Robertson, F.R.S., has made a study of self-diffusion in anthracene single crystals, using a radioactive-tracer technique.

A method was developed for the growth of large single crystals of anthracene from the melt, starting from the Bridgman technique. On to one surface of the crystals was evaporated a deposit of anthracene 9-carbon 14, prepared by a seven-stage synthesis from barium 14-carbonate, and the crystals and their deposits were heated at constant temperatures in the range 150° to 190°C for periods up to 230 hr. The crystals were then sectioned parallel to the initial active

face, using a calibrated, hand-operated lathe. The quantity of radioactive material that had diffused into each section was determined by quantitative combustion of the sections to carbon dioxide in an "empty tube" rapid-combustion apparatus, followed by the determination of the disintegration rate of this gas in a gas counting tube, using carbon disulphide as charge transfer agent. Penetration was found up to a depth of 4×10^{-2} cm.

It was found that two concurrent diffusion processes were occurring in the crystal. One of these involved only a small proportion of the total diffusing activity and may represent diffusion along intersecting dislocations in the crystal. The second process involved most of the diffusing activity and was thought to represent bulk diffusion in the crystal. The temperature dependence of the diffusion coefficient for this second process is given by :—

$$D = (1{\cdot}31 \pm 1{\cdot}13)\ 10^{11} \exp\left[-(42{,}400 \pm 1{,}200/RT\right] \text{ cm}^2/\text{sec}.$$

The pre-experimental factor and activation energy for this process are unusually high. The conclusion, therefore, seems to be that a co-operative diffusion is occurring in the crystal, in which diffusion occurs by way of vacant lattice sites, and that the loosening or pre-melting of from four to six molecules occurs in the neighbourhood of the vacancy during diffusion.

(3) Mr. A. Richmond

Mr. Richmond held his scholarship in the University of Oxford, under Sir Cyril Hinshelwood, O.M., F.R.S., where he investigated the mechanism of gaseous oxidation process. The investigation was in two parts, the first being concerned with the kinetics of the slow oxidation of carbon monoxide in the presence of water vapour.

The carbon monoxide/oxygen system shows a low-pressure explosion peninsula, a feature believed to be characteristic of gaseous chain branching reactions. The occurrence of such a peninsula in the hydrogen/oxygen system has been satisfactorily explained and a detailed mechanism developed for the oxidation process. The understanding of the mechanism of the oxidation of carbon monoxide is far less complete, and this is undoubtedly due, in part, to the pronounced influence of trace water on the reaction.

At pressures above those of the upper boundary of the explosion peninsula, carbon monoxide is oxidised at a measurable rate, in the presence of water vapour. A detailed investigation of the kinetics of this slow oxidation process is presented by Mr. Richmond. The influences on the rate of reaction of reactant composition, of the surface / volume ratio of the vessel, and of added inert gas were studied in the temperature range 572° to 622°C.

An increase in any one of the reactant partial pressures, or the addition of an inert gas, reduced the rate of reaction when the original mixture composition was close to that of the second explosion limit. An increase in the surface / volume ratio of the vessel reduced the rate of reaction for all mixture compositions, but the effect was greatest when the partial pressures of oxygen and carbon monoxide were large and that of the water vapour relatively small. The overall energy of activation of the reaction varied in a complex manner with the mixture composition and the surface / volume ratio of the vessel.

The experimental results agree with a postulated mechanism for the oxidation in which reaction chains are initiated by a heterogeneous reaction between carbon monoxide and water vapour, and in which the second explosion limit is determined by reactions of the type

$$X \longrightarrow Y$$
$$Y + B \longrightarrow nX \quad \text{where } n > 1$$
$$Y + B + M \longrightarrow M + \text{inert product}$$

It is suggested that oxygen may favour reaction through a linear chain reaction, which is inhibited by an increase in the surface / volume ratio of the vessel. The simultaneous occurrence of a branching chain process (favoured by water vapour) and a linear chain process (favoured by oxygen), both processes being inter-related, may explain a number of the complexities of the carbon monoxide/oxygen system.

The second part of Mr. Richmond's investigation was into the kinetics of oxygen atom recombination. The study of the elementary reactions of atoms and radicals is of value in the elucidation of the mechanism of gaseous chain processes. The reactions of oxygen atoms are particularly important in combination processes, and this investigation represents an initial study of the rate of recombination of oxygen atoms at room temperature.

Molecular oxygen was dissociated in either a radio-frequency or microwave electrodeless discharge, and the subsequent rate of recombination of the atoms was followed, along a reaction flow tube, by the technique of isothermal calorimetry.

The observed heating effect in dry oxygen decayed exponentially with distance along the flow tube, and, hence, with time. The derived decay rate constants showed a random variation and also increased as the linear flow velocity was raised, at constant pressure. A correction for the diffusion flow of atoms failed to eliminate completely this dependency upon flow speed, but the results suggest a linear relationship between the decay and the pressure of oxygen. Experiments with wet oxygen showed that the heating effect again decayed exponentially with time, but at rates that were slower than those for dry oxygen. After correction for diffusive flow of atoms, it was found that the decay rate varied linearly with the square of the oxygen pressure.

Mr. Richmond concludes that the main decay process in wet oxygen is due to atom recombination, a residual slower decay in some experiments being possibly due to the rate of de-activation of oxygen molecules in the $(^1\Delta g)$ excited electronic state. The initial more rapid decay process in the dry gas may be due to another excited electric state of molecular oxygen, or to an ionic species. The slower decay rates observed in certain cases in the dry gas, particularly in the presence of argon, are possibly due to atom recombination.

(4) Mr. K. J. Reid

Working in the University of Cambridge under Professor T. R. C. Fox, and later under Professor J. Monteath Robertson, F.R.S., in the University of Glasgow, Mr. Reid studied mass transfer at liquid interfaces.

Although mass transfer operations find an extensive application in industry, there have been relatively few fundamental investigations into the nature of the process. Mr. Reid presents a theory, derived from first principles, for the absorption of a sparingly soluble liquid into a thin flowing spherical film of a second liquid, and gives experimental results confirming the theory. A further check on the theory was obtained by absorbing the vapour into the flowing film and comparing the two experimentally determined diffusivities for the same fluid. The values obtained agreed within the limits of experimental error.

The column of spheres has found considerable favour as a laboratory model of industrial absorption equipment, but transfer rates have been increased by mixing effects at the junctions, and by ripples. These effects have not been separable in gas absorption experiments. Mr. Reid reports the use of a dye technique for experiments in gas/liquid and liquid/liquid systems. Absorption experiments in the liquid/liquid system gave an insight into this problem, and, in particular, demonstrated the nature of the flow through the

junctions between the spheres, and suggested that the two effects of mixing and rippling are not independent.

The nature of stagnant surface films is discussed and a theory presented for absorption into a thin flowing liquid stream with a stagnant film at the interface. The theory assumes no resistance to transfer through the stagnant film itself and shows that transfer rates can be reduced by about 70 per cent, due to the change in the hydrodynamics of the flow alone.

Experiments in a packed column with zero continuous-phase flow rate enabled point values of individual film coefficients to be determined.

(5) Mr. D. Wilson, working in the University of Birmingham, under Professor F. H. Garner, O.B.E., is studying a problem in gas absorption. He has not yet completed this work, and the report on it will, therefore, be held over until next year.

In this Issue...

E. A. K. Patrick

E. A. K. Patrick was educated at Christ's Hospital and Birkbeck College, University of London, and graduated with honours in Chemistry. By part-time study, he subsequently became qualified as a Chemical Engineer and in 1945 was awarded the Macnab Medal of The Institution of Chemical Engineers. Mr. Patrick joined the staff of the Fulham Laboratories of the Gas Light and Coke Company in 1939, and transferred to Watson House in 1945 as second-in-command of the Industrial Laboratory, of which he is now the Officer-in-Charge Mr. Patrick is the author or co-author of a number of papers presented to this and other bodies, and is a member of Council of The Institution of Chemical Engineers, and of the Board of Examiners and other Committees of that Institution. At present, he is Junior Vice-President of the London and Southern Junior Gas Association.

N. G. Patel

N. G. Patel was born in the Union of South Africa, where he was educated at the Johannesburg Indian School. He received university education at the Battersea College of Technology and in 1956 graduated with honours in Chemical Engineering in the University of London. After a period of one year in the process design department of Foster Wheeler, Limited, London, he paid a short visit to India. In 1957, he joined the staff of the Industrial Laboratory at Watson House, where he is engaged in research on combustion and heat transfer problems.

EXPERIENCES WITH BRANCHED-FLUE AND SE-DUCT SYSTEMS FOR VENTING GAS APPLIANCES

By W. J. Bennett, M.Sc., B.Sc.(Eng.), Assoc.M.Inst.Gas E., and C. H. Purkis, B.A., B.Sc., M.Inst.Gas E., A.M.I.H.V.E.
London Research Station, The Gas Council
and
J. B. Carne, B.Sc., and T. T. White, B.Sc., A.R.C.S.
Central Laboratories, South Eastern Gas Board

Research Communication GC72
(*Continued from p.* 134.)

Table of Contents

		Page
V	The U-Duct System	187
VI	Conclusions	188
	Acknowledgments	188

Appendices

1.	—Instrumentation of Shared Flues	189
2.	—Wind Tunnel Tests on Scale Models of Buildings	191
3.	—Usage Factors for Instantaneous Water Heaters	193
4.	—Duct Flows and Temperatures Under Wind Conditions	194
5.	—Performance of the Se-Duct System : Theoretical Considerations ..	197
6.	—Symbols	199
7.	—Literature References	199
	Presentation, Discussion and Reply	200

V THE U-DUCT SYSTEM

The U-duct form of shared flue was first proposed by Dick in discussing an earlier paper[3] to The Institution of Gas Engineers. The idea was investigated in the laboratory and the experimental results reported in a further paper.[4] It was shown that close agreement could be obtained between the experimental flow rates and predicted values.

So far as is known, only one U-duct serving more than one appliance has so far been constructed and put into operation in a block of flats; this is at Eastbourne. The installation has a number of novel features, some of which have operated against an adequate appraisal of the system as a whole: for example, the appliances were of an unusual and experimental pattern, the ducts were not constructed from flue blocks and were far from airtight. Nevertheless, the potentialities of the U-duct are such that the following brief account of experimental observations on it may be of interest.

The installation is used to ventilate the combustion products from air heaters in a three-storey block of six flats. The ducts were constructed from 1 in. marinite slabs coated with an acid-resisting sealing compound, and pre-formed into 6 ft sections. Four slabs formed the outer walls of the ducts, and a further internal slab arranged centrally formed a subdivision into two ducts. The overall dimensions of the section of the ducts were 20 in. × 10 in., giving two internal sections of 8¼ in. × 7⅞ in. each, and a cross-sectional area of 0·45 sq. ft. The division slab terminated 1 ft 6 in. above the base of the system, to form the U, and an inspection panel was provided at this point. At the upper end of the system, in the roof space, the duct work was extended in sheet aluminium to pass through the roof into a combined inlet and outlet terminal louvred on all sides.

To facilitate measurement of conditions in the ducts, "Perspex" panels were fitted over apertures cut in the ducts in the roof space. The panels enabled the interior of the ducts to be viewed, and plugged holes in the plates permitted instruments to be inserted. As the duct was fabricated from sections, the system was tested for air-tightness before commencing other tests. Under a pressure of 0·2 in. w.g., a leakage rate of 1,700 cu. ft/hr was obtained. Unfortunately, it was not possible to rectify these leaks, owing to constructional difficulties.

The system was designed so that under the worst conditions (i.e., with all the appliances alight), the concentration of carbon dioxide at the top of the duct should not exceed 2 per cent. This is the same design criterion as used on the Se-Duct, but closer agreement between theory and experiment is to be expected in the case of the U-Duct because of the balanced termination. Evaluations of the concentration of carbon dioxide made in the duct with the heat input to each appliance set at 50,000 B.t.u./hr confirmed the expectations, as will be seen from Table 29.

TABLE 29—*Concentrations of Carbon Dioxide in a U-Duct Installation*

Appliances in Use	Concentration of CO_2 (per cent)
1	2
No. 1	0·9
No. 3	1·1
No. 1 and 2 ..	1·5
No. 2 and 3 ..	1·5
No. 1, 2 and 3 ..	1·9

The internal surface of the products duct was inspected through the " Perspex " panel after the three appliances had been in operation for approximately 15 min., at which time the concentration of carbon dioxide was 2 per cent. Drops of condensation were present on the walls, but the quantity was not sufficient to run, and after the appliances had been in operation for approximately 30 min. the condensate had re-evaporated.

To determine the degree of heat transfer from the products duct to the inlet duct, temperatures of the inlet air were measured near the top and base of the latter. After three heaters had been in operation for 90 min., the temperature at the top of the duct was found to vary between 72° and 86°F; the temperature at the base was 68°F, with an outside air temperature of approximately 58°F. Some heat transfer was taking place by air recirculation and, no doubt, occurred through the aluminium dividing wall; it was, however, evident that the total heat transfer throughout the duct length was small.

The base of the U-duct was below ground floor level, where there are open construction sleeper walls supporting the wood floors; this region was ventilated by air bricks around the building, so that a neutral zone was formed. The access panel was removed and the air inlet duct sealed at the base to form a Se-Duct. With the heaters de-rated to 45,000 B.t.u./hr, a 1·1 per cent concentration of carbon dioxide was obtained with all three in operation.

It is clear that, subject to the constructional and other limitations already referred to, the U-duct is performing satisfactorily and in good agreement with prediction. At the same time, these tests draw attention to the importance of sound construction and correctly designed appliances, if optimum performance is to be achieved.

VI CONCLUSIONS

The measurements carried out in the field investigations of shared flues have provided data that are not only essential to the basis of design of the systems, but also further the understanding of the performance of flues generally. The instrumentation has yielded information, on the pattern of appliance usage in both the branched-flue and Se-Duct systems, that is indispensable to the economic design of the systems, and which could be provided in no other way. Hitherto, the values assumed for this usage have been based on a general consideration of consumers' requirements and have, therefore, been more in the nature of an intelligent guess; the measured values, which are lower than generally estimated, may also have application to the economic sizing of the gas and water supply pipes in similar blocks of flats.

The measurements obtained on the branched-flue systems investigated have confirmed consumers' experience that, in a well designed system, downdraught occurs to a degree so small as to be insignificant. The importance of correct design and exposure of the terminal, previously appreciated by field observations, has been confirmed by a laboratory-model technique, the development of which may be of great assistance in ensuring satisfactory performance of future installations. The field of application of the branched-flue system has been extended as a result of this work, mainly by an increase in the permissible numbers of appliances connected to one main flue and by a clarification of minimum heights of subsidiary flues; revised design data are set out in detail in the paper.

The comprehensive records obtained at the Gateshead installation, together with data from other installations, have shown flow conditions in the Se-Duct system to be remarkably stable and have provided the material for a theoretical analysis that enables the energy factors to be assessed quantitatively and thus to explain the reasons for this stability. The work has also confirmed the validity of the basic principles of design of the Se-Duct system as originally formulated, and provided a firm basis for a reduction of the recommended sizes of Se-Ducts for flats above seven storeys high, and a somewhat less restrictive use of single inlets. Downward flow in the duct due either to natural temperature inversion or to wind effects occurs but rarely and is completely insignificant, confirming that satisfactory performance of the system does not depend critically on the design and location of the terminal. Observation has also confirmed that the incidence of condensation in the system is negligible.

Although a considerable amount of valuable technical information has been obtained from the investigations described, more is required to complete our knowledge on some fundamental aspects. Two gaps that obviously remain to be filled are a more detailed knowledge of the pattern of wind flow and pressure around buildings and the pattern of simultaneous usage of appliances, particularly space heaters. Clearly, we have progressed beyond the pragmatic use of systems in which the design must be subject to a pattern of rolling readjustment, but the programme of research must be continued to enable the most economic systems to be designed.

Acknowledgments

It will be apparent from the nature of the investigations dealt with in this paper that many people have contributed to whatever results have been achieved; to single out individuals for special mention would perhaps be invidious.

The authors are specially indebted to those architects, borough corporations and councils, and building contractors, that have generously afforded facilities for experimental work, and to the Tyne Improvement Commission for making available the wind records used in the paper.

They wish to thank the Area Gas Boards for providing some of the photographs that appear in the paper, and for the ready co-operation of their district staffs. Particular mention should be made of the help received, during a period of some three years, from the laboratory staff of the Northern Gas Board, without whose constant vigilant care of the instruments at the Gateshead installation the comprehensive records could not have been obtained.

They would like to thank their own colleagues who have carried out much arduous work in the field; those in the

Aerodynamics Laboratory at Watson House who carried out the experiments on model buildings ; and those of the Instrument Section of the South Eastern Gas Board Central Laboratories who devised and constructed the appliance usage recorders for the Gateshead installation.

Finally, the authors record their appreciation of the guidance and encouragement they have received from the Director of the Watson House Centre and the Manager of the South Eastern Gas Board Central Laboratories, and their thanks to The Gas Council and to the North Thames and South Eastern Gas Boards for permission to prepare and publish this paper.

APPENDIX 1

INSTRUMENTATION OF SHARED FLUES

The reasons for instrumenting district installations of shared flues, and the measurements required, have already been discussed. In obtaining the required results, however, two basic problems have to be resolved:

(i) Choice of the most convenient method of automatic recording of information, and selection of suitable instruments.

(ii) The analysis of the records so obtained.

In the first case, the equipment should be sensitive and accurate, robust and reliable. In general, difficulty is experienced in obtaining all these qualities simultaneously to a satisfactory degree, and some compromise is necessary. Secondly, to analyse large quantities of records some form of automatic analysis is necessary if the results are to be obtained at an economic cost. Since the first branched-flue installation was instrumented, much experience has been obtained and many improvements effected in the instrumentation of shared flues, and it seems, therefore, appropriate to record the essentials of this development.

(A) Branched Flues

The method of instrumenting branched-flue installations has already been described.[6] The observations required consisted of measurements of the pressure difference between a subsidiary flue and the corresponding room, *via* pressure tubes connected to a sensitive micromanometer in a convenient instrument room, the observations being recorded on a multipoint potentiometric recorder. To ascertain which appliances connected to the flue were in use at any instant, thermocouples fitted in the subsidiary flues had leads run also to a recorder in the instrument room.

Manual analysis of the appliance usage charts presented relatively little difficulty, since characteristic exponential heating and cooling occurred and each point was separately numbered.

Analysis of the pressure readings was much more difficult. The recorder pen printed dots on the chart every 6 sec, which, on a two-point recorder, meant once every 12 sec for each measuring point. The displacement, relative to a zero position, of each dot represented a pressure measurement, and the problem was to obtain the number of dots within each of certain specified pressure ranges, thus enabling the total period of time over which these conditions occurred to be determined. If adverse pressures occurred at all frequently, then the counting of dots in, say, five specified ranges for each recording point was tedious and time-consuming.

Consideration is now being given to the automatic counting of the number of times that a dot is printed between the stipulated pressure limits, using the spindle that positions the pen of the potentiometric recorder. The angular rotation of this spindle is proportional to the linear traverse of the pen, and hence, if micro-switches are positioned around the periphery of a cam mounted on the spindle, as shown in Figure 21, these may be so adjusted in position that they are

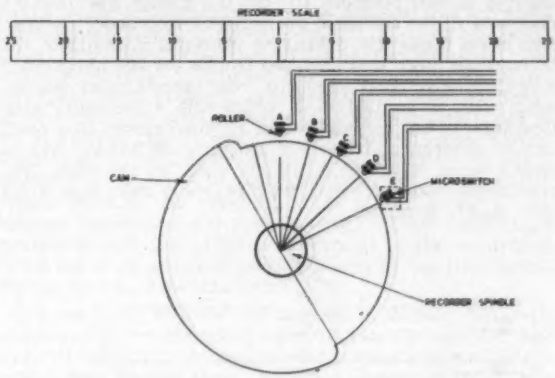


FIGURE 21.—*Branched-flue Instrumentation: Automatic Counting Device—1.*

closed only when the pressure differential reaches the desired limits. Figure 21 shows the positions of five switches that will be closed as the adverse pressure differential passes zero, 5, 10, 15 and 20 thousandths in. w.g. Referring to Figure 22, when a particular micro-switch is closed by the cam the electro-mechanical counter will count every time the recorder selector switch makes contact for a particular input point, and the pen mechanism is about to print. If, for instance, a steady downdraught of 0·011 in. w.g. is being measured, switches A (0·000), B (0·005) and C (0·010 in. w.g.) will be closed, and counters A, B and C will count, every time the selector switch is in position 1, and the pen mechanism micro-switch is closed, that is, every 12 sec.

As it stands, this arrangement could be used only to obtain the required pressure measurements over the total time; it does not analyse separately the pressure records obtained when an appliance connected to the system is in use. This could be carried out, however, by an extension of the principle, using a second counter system connected in parallel with the first, such that, if the first is counting, the second will only count when a switch is closed, by a relay controlled by a pressure switch operated by turning on any one or more of the relevant appliances.

(B) Se-Ducts

The Se-Duct system is so designed that, under maximum likely working conditions, the concentration of carbon dioxide in the ducts will not be greater than 2 per cent. One object of the instrumentation was to determine the frequency with which this figure was approached or, if at all, exceeded. For this purpose, an infra-red gas analyser was used in conjunction with a recorder having a non-linear scale to an extent such that, for 2 per cent of carbon dioxide, well over a half-scale deflection was obtained. This was particularly convenient, since a high degree of accuracy could thus be obtained in the region where it was expected that the bulk of the readings would be recorded. The gas samples were drawn through a sampling tube in the duct a few feet below the terminal. It was necessary for the analyser to be installed close to the sampling-point, but the recorder could be remote from the sampling position.

Appliance operation records were used to make records of the times at which each appliance was in operation. The

electrical impulses came in each case from a pressure switch installed in the gas supply immediately prior to the burner. Two types of event recorder have been used; the one at Gateshead was constructed in the laboratory and consisted essentially of 12 pens, each recording on a chart and each capable of two positions so that the change from the de-energized to the energized position was recorded by a small step in the trace. The alternative instruments, available in a commercial form, were designed so that the pen moved over a heat-sensitive chart produced from special paper impregnated with silver oxide and coated with a protective wax. Operation of the pressure switch supplied energy to a small electric element, and the heat generated melted the wax to form a dense black line of metallic silver on the chart. The chart speeds were such that heater usages of more than 30 sec were readily detectable.

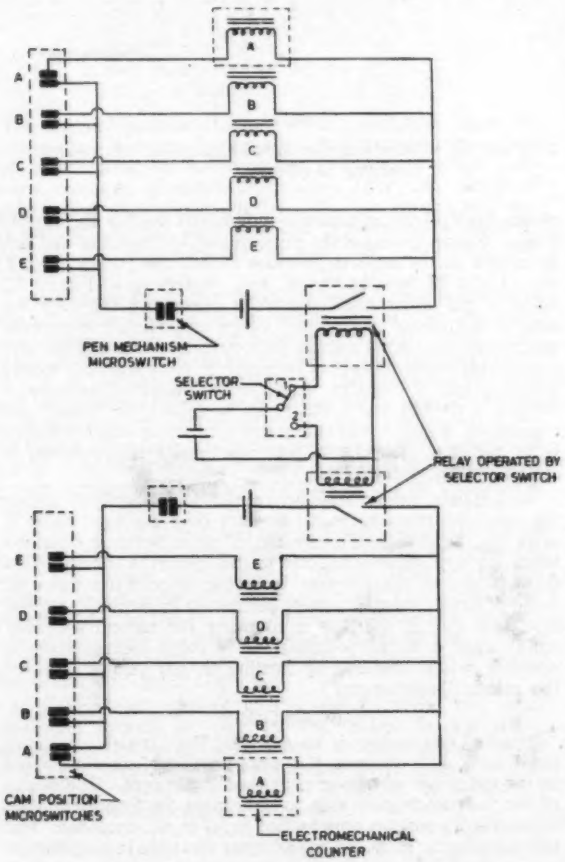


FIGURE 22.—*Branched-flue Instrumentation: Automatic Counting Device—II.*

The determination of the flow of air and products in the Se-Duct was probably the most difficult measurement to obtain with accuracy. In the Gateshead installation, it was considered necessary to measure the rate of flow both in the horizontal base duct and also in the vertical duct and the instrumentation had to be capable of recording a maximum velocity of some 12 ft/sec, a normal velocity of 3 to 5 ft/sec, and occasionally a flow reversal in the duct. It was not possible to provide any one instrument that would meet all these requirements and so two different types were employed. To measure flow in the range 0 to 5 ft/sec, two hot-wire anemometers were used of the type now manufactured from the original pattern by L. S. G. Simmonds.[13] The outputs of the thermocouples were recorded on a potentiometric-type recorder, the recorder scale being arranged so that flow rates recorded by each anemometer occupied one-half of the chart. The actual calibration of each anemometer was non-linear, maximum sensitivity being obtained in the range 0 to 5 ft/sec.

The hot-wire anemometers used were non-directional devices giving exactly the same response, whatever the direction of flow. Since flow reversals were possible and it was essential that these should be recorded, an immersion venturi type of flow-measuring device was added. These devices, although of lower sensitivity than the hot-wire anemometers, were potentially capable of recording flows of as little as 3 to 4 ft/sec, and the results were directional. Therefore, by using two venturis back-to-back in each of the ducts to be explored, it was thought possible to detect the changes in the direction of flow even though considerable percentage errors were possible at low flow rates. Experience showed that the hot-wire anemometers were relatively successful at Gateshead except for the fact that the calibration tended to change with time. The immersion venturis, however, were not so successful and were quite unsuitable for making measurements in the range ± 1 ft/sec. It was subsequently decided to make use of a double Pitot tube in conjunction with a sensitive micro-manometer.

The most difficult charts to analyse were those from the event recorders used at Islington, since it was desired to assess the number of appliances in operation at any one time and at what periods of the day or week such times predominated, and this necessitated the lining up of very small marks on 20 traces. An experimental scheme of electrical integration, based on the commercial form of the operation recorder, was developed in the following manner.

FIGURE 23.—*Islington: View of Instrument Room.*

The pens of this instrument are operated by an electromagnet consisting of a solenoid wound to a fixed resistance of 500 ohms fitted over a soft iron core. From an integral transformer rectifier, the solenoids are each fed with current at a constant pressure of 24 V d.c. through the contacts of the pressure switches, and so each coil passes a constant current of 48 mA when in operation. Thus, when one coil is energized, this current is drawn from the rectifier; two coils take twice as much, and so on. The rectifier circuits were, therefore, reconnected to incorporate, in series, a recording continuous pen ammeter. Thus, when used in conjunction with a suitable shunt resistance, the ammeter reading was a measure of the number of appliances in use at a particular instant. It did not, of course, indicate which appliances were in use. Over a given period, the chart record obtained was in the form of a histogram, which proved much easier to analyse than the operation recorder charts.

The instrumentation of a typical Se-Duct installation is shown in Figure 23.

APPENDIX 2

WIND TUNNEL TESTS ON SCALE MODELS OF BUILDINGS

Three "Perspex" scale models of the Holborn branched-flue installation (Figure 24) were subjected to laboratory wind tests and the results compared with those obtained in practice. The scales were 1/96, 1/192 and 1/384. With the limited wind front available in the laboratory, the maximum convenient model height was 1 ft. It was thought that by testing three models with size ratios 1 : 2 : 4 any serious scale effects would be detectable. The models were placed on a turntable at the centre of a ground plane 8 ft × 4 ft and subjected to a 3 ft wide and 18 in. high wind front. The arrangement had prvoed satisfactory in earlier experiments on wind pressure distribution around houses when good agreement had been achieved with previous published data referred to in the bibliography of the paper by Wills, *et al.*[7] To maintain dynamical similarity between the model and the full-sized building, it would be necessary to increase the wind velocity on the model by the scale ratio, and, if it is assumed that the mean natural wind speed is about 9 m.p.h., a supersonic wind tunnel would have been required for these experiments. The earlier workers have, however, found that good comparative agreement can be obtained using very much lower wind speeds, and for the series of experiments an operating wind speed of 9·1 m.p.h. was chosen, since this represents the mean annual wind speed for reasonably exposed sites. The flue was represented by a length of $\frac{1}{8}$ in. brass capillary tubing, which could project through the "Perspex" base of the model at the terminal position to any desired height. Experiments were performed with this probe projecting to heights equivalent to the top of the terminal base in the original installation and also to the top of the tank room roof.

Figures 25 to 30 show the variation in induced flue static pressure with incident wind angle. It must be assumed that with tall buildings the incident wind stream is generally horizontal even though there may be a superimposed rolling motion. This will be true in most installations, but it is impossible to simulate plunging wind effects accurately in the laboratory, due to the large-scale difference between the model and the ground plane. The first series of experiments were designed to compare the induced flue pressures obtained with the three sizes of models. The results are given in Figures 25 and 26 for the models of the complete building freely exposed at the centre of the ground plane with the probe at the heights of the original stack and extended to the tank room roof level respectively. In both cases, the characteristic curve shapes are similar, but the magnitude of the induced pressures depends on the model size, with the largest pressures produced with the largest model. This is most probably due to the

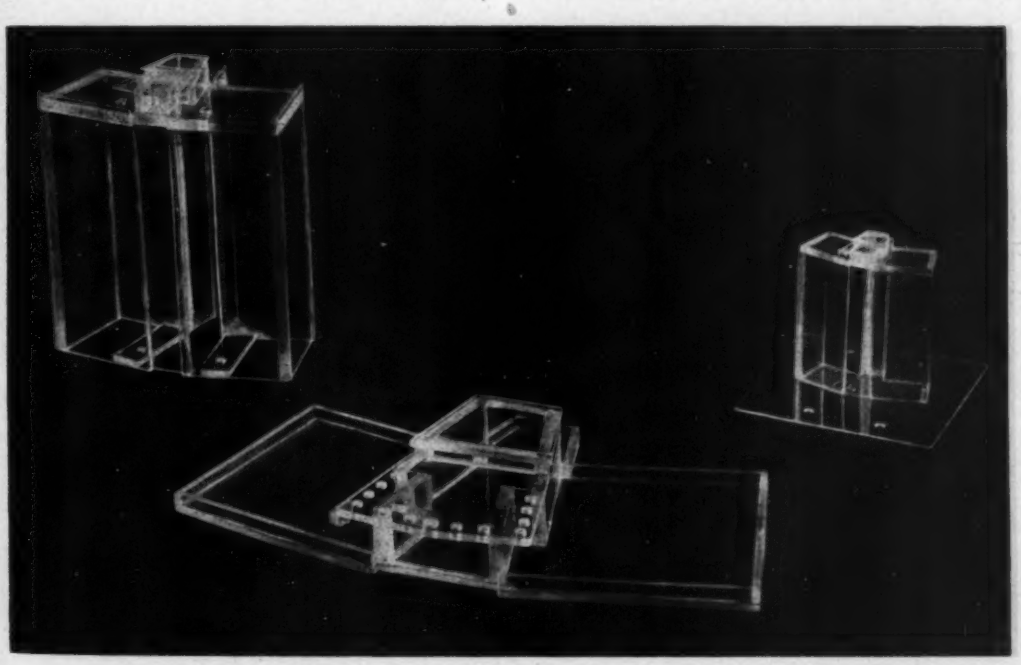


FIGURE 24.—*Holborn: Scale Models.*

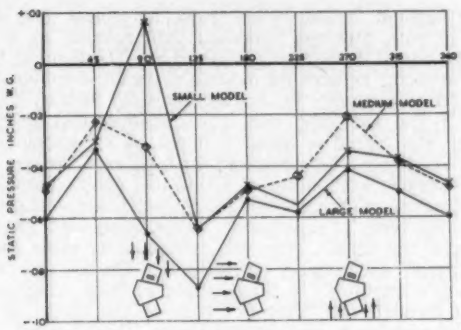


FIGURE 25.—*Holborn Model Tests: Variation of Induced Flue Static Pressure with Incident Wind Angle (I).*

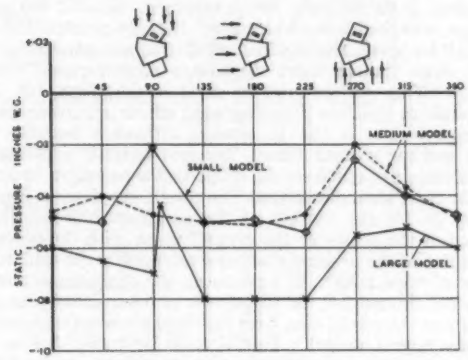


FIGURE 26.—*Holborn Model Tests: Variation of Induced Flue Static Pressure with Incident Wind Angle (II).*

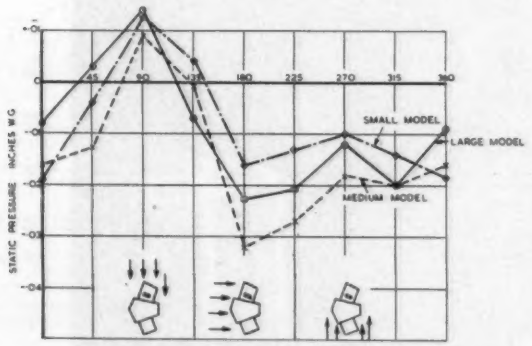


FIGURE 27.—*Holborn Model Tests: Variation of Induced Flue Static Pressure with Incident Wind Angle (III).*

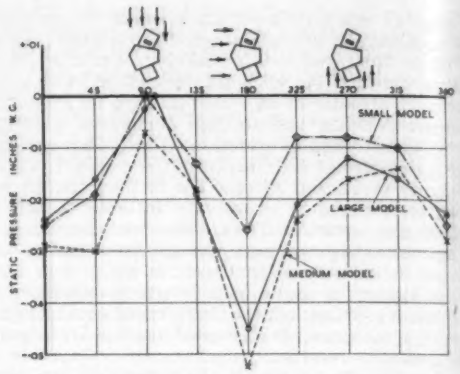


FIGURE 28.—*Holborn Model Tests: Variation of Induced Flue Static Pressure with Incident Wind Angle (IV).*

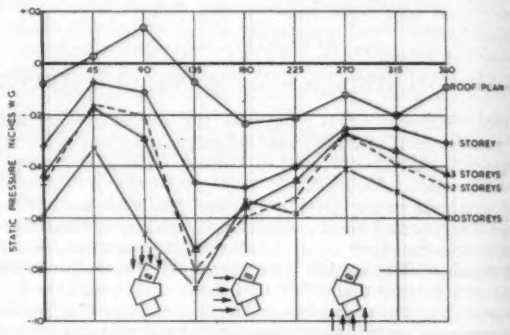


FIGURE 29.—*Holborn Model Tests: Variation of Induced Flue Static Pressure with Incident Wind Angle (V).*

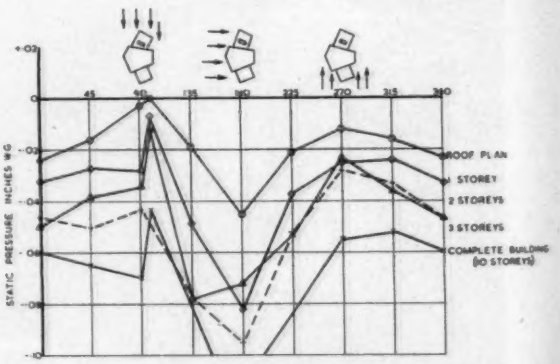


FIGURE 30.—*Holborn Model Tests: Variation of Induced Flue Static Pressure with Incident Wind Angle (VI).*

velocity gradient away from the ground plane surface. The disturbing feature of these results, apart from the size effect, is that only with the smallest model is downdraught indicated around the 90° position as was experienced in practice. However, these freely exposed tests did not represent the practical installation because Poole Building was surrounded by older blocks of flats of similar height. It was found that downdraught could be caused with the complete building by placing upstream obstacles in front of the building. Whilst it was not possible to construct a complete model of the building and its environment, it was considered reasonably representative of the natural conditions to construct model roof plans with the ground plane at roof level. The results of these experiments are given in Figures 27 and 28 for the three model roof plans with the probe at the original stack height and extended to the tank roof level respectively. Generally, similar curves were obtained with the three models and there was no indication in this case that the greatest pressures were produced by the largest model. Also, all models exhibited serious downdraught in the 90° position,

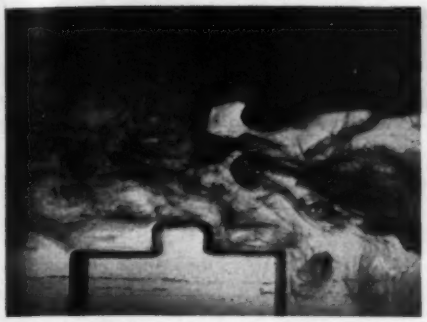


FIGURE 31.—*Holborn Model Tests: Flow Patterns (I).*

FIGURE 32.—*Holborn Model Tests: Flow Patterns (II).*

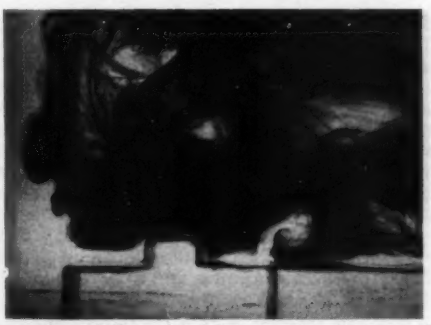


FIGURE 33.—*Holborn Model Tests: Flow Patterns (III).*

which was eliminated when the stack was extended to the tank room roof level. The minimum pressures were recorded, as expected, in the 270° orientation when the probe was shielded from the incident wind by the tank room. These results were in agreement with those obtained at the installation and suggest that the roof-plan type of wind test may yield results that are valid in practice.

To investigate further the effect of the roof height relative to the ground plane, experiments were conducted with the roof plan only, and in turn the roof plan plus one, two, three and 10 storeys (the complete building) above the ground plane with the probe first at the original stack height and then extended to the tank room roof level. These results are detailed in Figures 29 and 30 respectively. In both cases, the magnitude of the induced updraught increases with the height of the roof above the ground plane. For these experiments the largest model size was used.

To determine the wind flow pattern around the complete building and also around a roof plan ground plane, a simple building elevation was constructed in aluminium and placed in a water flow tank. Figures 31 to 33 show the water stream lines obtained using ink as a tracer for the freely exposed building, the building with a high neighbouring obstacle on the windward side, and a ground plane at roof level respectively. With the complete building, the wind stream disturbances due to the top of the building face may rise above the tank room roof, and therefore, no positive pressure build-up can occur in front of the tank room. This explains why downdraught was not observed with two of the three complete building models with the probe at the original stack position. With the windward obstacle, the vortices shed from the obstacle edge cause some pressure build-up at the tank room. Finally, with the wind blowing horizontally along the ground plane and roof, the full wind effect and positive pressure build-up is observed at the tank room wall. This appears to represent the most rigorous test condition in agreement with the wind experiment.

APPENDIX 3

USAGE FACTORS FOR INSTANTANEOUS WATER HEATERS

In designing shared-flue systems, it is necessary to assume a certain usage factor for the connected appliances. In the case of space heating appliances, it is inevitable that a 100 per cent usage factor must be adopted; with instantaneous water heaters, however, there is no doubt that a much lower figure can be used. In the case of the Se-Duct, an arbitrary value of 30 per cent has so far been adopted, irrespective of the total number of appliances. The purpose of this Appendix is to examine the usage factor, from a statistical point of view, and its relation to other factors.

(A) THEORY

If P is the probability of an appliance being in use at any instant in a given period, then it is easily shown[14] that the probability of k such appliances, from a total of N, being in use at the same time is given by the $(k+1)^{th}$ term in the binomial expansion

$$(Q+P)^N \text{ where } P+Q=1.$$

In theory, this is not strictly accurate, since a constant probability of use cannot be assumed, by virtue of the different standards of consumers. However, it can be shown that, for the range of individual heater probabilities found at Gateshead and Islington (i.e., maximum to minimum usages of 10 to 1), no significant error is introduced by use of the above expression. Hence,

$$\begin{aligned}\text{Probability of 0 appliance} &= Q^N\\ \text{,, 1 appliance} &= {}^NC_1PQ^{N-1}\\ \text{,, 2 appliances} &= {}^NC_2P^2Q^{N-2}\\ \text{,, } k \text{ appliance} &= {}^NC_kP^kQ^{N-k}\end{aligned}$$

Hence, in a period of T hr, it is to be expected that any k heaters will be in use for

$$T^NC_kP^kQ^{N-k}$$

although this period will be composed of a number of much smaller ones. Provided that this period is insignificant, the use of k appliances can be ignored and design based on $(k-1)$ heaters in simultaneous use. Hence, if t hr is the criterion for insignificance, the design number of appliances is given by $k-1$ where

$$T^NC_kP^kQ^{N-k} < t \quad . \quad . \quad . \quad . \quad (1)$$

(B) Observed Probabilities

Long-term records have been obtained for the water heater usages at Gateshead and Islington. The physical problem of analysis has limited the information that can be derived from them, but sufficient has been obtained to enable reasonable estimates of usage probabilities to be made. Tables 13 and 15 show that the probabilities are small, but only enable the mean values over a week to be calculated. In practice, there are certain periods of the week (such as "bath night" and "Sunday lunch") when usages of several times the mean are to be expected. However, no analysis was made of the distribution of the use of single heaters.

This analysis was, nevertheless, carried out for the simultaneous usage of any two appliances at both Gateshead and Islington. Figures 9 and 10 show this distribution for the 10 appliances at Gateshead over a 23-week period, and for the 20 Islington heaters for a 21-week duration. It can be seen that the general distribution was the same in the two cases, with the exception that the Saturday "bath night" peak is missing at Gateshead.

At Gateshead, the maximum two-appliance usage occurs between 10 a.m. and 11 a.m. on Sunday. In 23 such hours, a total usage of 37 min. was recorded. Hence,

$$^{10}C_2 P_G{}^2 Q_G{}^8 = \frac{37}{23 \times 60}$$

Whence,

$$P_G = 0{\cdot}027$$

Similarly, at Islington, the peak usage was at the same time, and 90 min. usage was recorded in 21 hr. Thus,

$$^{20}C_2 P_I{}^2 Q_I{}^{18} = \frac{90}{21 \times 60}$$

giving $P_I = 0{\cdot}024$.

Hence, similar figures were obtained from each installation for the probability of usage of an appliance. Thus, if these figures are increased to, say, 0·03, we have an over-estimate of the usage in this type of property for use in calculations.

(C) Theoretical Probabilities

The observed probability, although agreeing for the two installations on which records were obtained, must be regarded as low. Both installations were local authority dwellings and the overall usage figures were low compared with the generally accepted consumptions. It is, therefore, of interest to consider a theoretical maximum value of the probability.

Assume that on the "bath night" period of peak usage, extending for, say, 4 hr, each appliance is used for two 15-min. bath draw-offs. This gives the theoretical probability

$$P_T = \frac{2 \times 15}{4 \times 60} = 0{\cdot}125$$

or about five times the practical figures.

(D) Design Probabilities

Obviously, the practical maximum is likely to be somewhere between the observed and theoretical probabilities, and in the absence of further information a figure of $P = 0{\cdot}1$ is assumed for the subsequent calculations. This probability should apply to the peak period only, and it is considered that 10 hr/week will amply cover this.

The period of acceptable simultaneous use will be taken as 10 min./week, since this period will be composed of a number of much smaller intervals. The figure is, however, quite arbitrary and may be modified when further information becomes available.

Hence, with these figures, equation (1) becomes

$$^{N}C_1 (1/9)^1 (9/10)^N < \frac{1}{60}$$

Using this expression, Table 30 has been calculated, given the design numbers for various total numbers of appliances.

TABLE 30.—*Design Numbers for Instantaneous Water Heaters*

Total Number of Appliances	Design Number
1	2
Up to 6	2
7 to 11	3
12 to 16	4
17 to 22	5
23 to 29	6

APPENDIX 4

DUCT FLOWS AND TEMPERATURES UNDER WIND CONDITIONS

Although it is proposed that the design of the Se-Duct system should be based on calm conditions, it is essential for a full understanding of the system that its performance under wind conditions should be analysed. This appendix considers the two cases of performance, with and without appliances in operation. Calculations, except where otherwise stated, are based on a 10-storey building with a 9 × 15½ in. duct.

(A) Without Thermal Effects

The flow in the two horizontal branches and the vertical branch when thermal effects are absent will depend on the magnitude of the wind pressures at the three openings of the system. The pressure distribution around the building will vary with a number of factors, as indicated on p.19. Recourse has been made to the published data on experimental studies of pressure distributions around models[11], and typical distributions have been selected for the purpose of illustrating the effect of wind on the flow through the duct. The pressures selected, expressed in terms of the velocity head of the wind, relative to the static pressure of the free wind stream, are + 1 for Y, the windward ground level opening, −0·5 for *Z*, the leeward ground level opening, and 0 to −1·0 for *X* at the terminal. (See Figure 34.)

As the flow rate through each of the three branches of the system is dependent on the pressure difference across the ends of the branch, the flow rates through each branch is dependent on the pressure *N* at the junction of the two horizontal branches and the vertical branch. When air is entering only the windward branch with a velocity V_y, the flow divides at the junction into two streams, one flowing along the leeward ground branch with a velocity V_z and the other flowing through the vertical duct with a velocity V_x.

As $V_x = V_y - V_z$ it follows that:

$$\sqrt{\frac{N-X}{R_x}} = \sqrt{\frac{Y-N}{1+R_y}} - \sqrt{\frac{N-Z}{R_z}} \quad . \quad (1)$$

where R_x, R_y, R_z are the resistance factors of the vertical duct and the windward and leeward ground branches respectively. For the instrumented duct, at Gateshead, when the north inlet is to windward, R_x, R_y, R_z have values of 6·2, 3·2 and 4·1 respectively, and for these values Table 31 has been calculated.

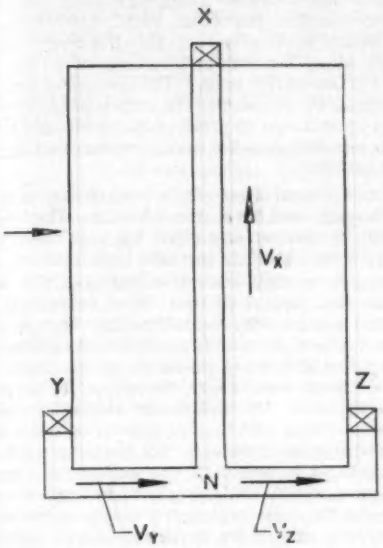


FIGURE 34.—*Se-Ducts: Diagram of Pressure Zones and Duct Velocities.*

The neutralizing effect of the ground branches on the pressure N at the base of the vertical duct is apparent from the table. When there is zero suction at the terminal, flows are established in the three branches such that, along the whole of the horizontal length, the pressure is almost neutral relative to the external pressures, and the pressure $N-X$ across the ends of the vertical duct is in a sense to produce an upward flow. As the suction, X, at the terminal is increased (i.e., additional pressure energy is supplied to the system), the flow into the windward branch increases, and as a consequence the pressure at N falls. Due to this inherent property of the system, the flow velocity in the vertical duct does not increase greatly as the terminal suction increases, and even with a high suction it is not excessive. Values of V_x for a wind speed of 20 m.p.h. are given in the table. For a tenfold change in X from $-0{\cdot}1$ to $-1{\cdot}0$, the velocity would increase 2·5 times.

TABLE 31.—*Gateshead: Pressures at the Base of the Vertical Duct Under Wind Conditions*

$Y = 1$; $Z = -0{\cdot}5$

Pressure at the Terminal (X) ..	0	−0·1	−0·5	−1·0
Pressure at the Junction (N) ..	+0·07	+0·02	−0·14	−0·30
$N-X$	+0·07	+0·12	+0·36	+0·70
Vertical Duct Velocity (ft/sec) (Wind speed 20 m.p.h.)	3·2	4·0	7·2	10·0

The pressure distributions required to produce a downward flow may be deduced by considering the limiting condition of $V_x = 0$ and zero suction at the terminal. For a system with the same pressure drop across each ground branch, the value of N when $V_x = 0$ would be the mean of the pressures at the extremities. A downflow condition would only occur, therefore, when the magnitude of the suction at the leeward opening exceeded the magnitude of the pressure at the windward opening. Experimental studies with models show that, for steady winds, this condition does not arise, Y being numerically greater than Z. Furthermore, under wind conditions, there would normally be a suction at the terminal, which would offset the effects of an unfavourable ground-level pressure distribution; the effects would be further offset by the basic thermal contribution to the duct air. At Gateshead, the pressures due to wind at the openings of the instrumented duct were deduced from the flows recorded in the branch limbs; a value for X of approximately $-0{\cdot}1$ was obtained. This deduction is strongly supported by supplementary observations, in the laboratory, on the static pressure produced within a similar terminal. Measurements were made with the terminal freely exposed, and also *in situ*, as at Gateshead, using a full-scale model of a section of the roof, and supported by additional tests made with a model housed inside a 3 ft square wind tunnel. For horizontal winds of up to 40 m.p.h. in any direction, the value of X was between $-0{\cdot}07$ and $-0{\cdot}16$. From Table 31, when $X = -0{\cdot}1$, the pressure at the base of the vertical duct is virtually neutral. The combined effect of this low suction at the top of the duct and a virtually neutral pressure at the base of the duct, for almost any ground wind-pressure distribution, is the basis of the remarkable stability of flow observed in the vertical duct.

The extent to which neutralization occurs for low values of X may be illustrated further by considering the effect of a 40 m.p.h. wind blowing towards the exposed north inlet of the duct.

For $X = -0{\cdot}1$, the pressure at N would be 0·02 in w.g. and the corresponding duct velocities 28·6 ft/sec into the windward branch 20·6 ft/sec out of the leeward branch, and 8·0 ft/sec upwards through the vertical duct. Air will enter a system with two ground branches through one or both branches, according to the relative magnitudes of the wind pressures and the thermal effects. For winds below 4 m.p.h., air will normally enter through both branches, and above 10 m.p.h. through the windward inlet only. The operation of the system in the intermediate conditions is discussed in Appendix 5. Where there are two ground level openings at right-angles (Figure 6(b)) the presence of the right-angle will not significantly alter the values of the pressure N in Table 31 for the same pressure conditions at the extremities.

(B) WITH THERMAL EFFECTS

The addition of thermal energy, T, to the vertical duct air produces a change in the flow rates in the three branches and a change in the pressure at N. The thermal energy is directly additive to the pressure energy in the vertical duct and may be considered as an increase in the magnitude of the suction at the terminal X. Hence, the flow may still be upwards even when there is a slight pressure at the terminal. With a thermal energy contribution of 1, calculations show that with $X = +0{\cdot}32$, and a 20 m.p.h. wind, the flow will just be upwards in the Gateshead ducts.

For $X = 0{\cdot}1$, calculations show that, for wind speeds up to approx. 20 m.p.h., the vertical duct air velocity is determined almost entirely by the thermal energy. For a wind speed of 40 m.p.h., the vertical duct air velocity is determined by the wind effect alone. The observed data confirm these findings.

The temperatures at the top of the vertical duct, when appliances are in operation under high-speed wind conditions, may be calculated from the corresponding flow rates in the vertical duct. An increase in duct air velocity from 4 to 8 ft/sec would result in a reduction in the temperature increments, due to heat transfer through the walls from 7·2° to 6·9° F and due to the pilot flames from 6·3° to 3·2° F. The effect of wind is thus to lower the temperature by only a few degrees, a conclusion that is supported by the measured data. With one appliance in operation, a 40 m.p.h. wind producing a suction at the terminal of $-0{\cdot}1$

would double the corresponding flow rate under calm conditions and thus halve the temperature increments. With the exception of heater 10, these findings are in accordance with the observed minimum values recorded in Table 24.

(C) Flow Through a System with One Air Inlet

The effect of wind on systems with one or two ground-level openings may be deduced from the earlier analysis. For a system with two openings, the wind pressures Y and Z produce a flow through the horizontal ducts and thereby a pressure at the base of the vertical duct, which is neutral to Y and Z; the closure of either inlet prevents this relief flow, and, hence, the flow through the system is dependent on the pressure Y or Z according to the exposure. It follows that, for a system with one opening, the upward flow rate would be higher or lower than for a system with two openings, according to whether the opening was to the windward or leeward.

The flows in the single-limb system are dependent on the combined effects of the sense and magnitude of the pressure difference between the openings and on the thermal effects. Information on the former may be obtained from the literature on experiments with models, but such data are limited to steady wind conditions of normal incidence and do not take into account effects produced by obstacles to the wind flow in a built-up area. This is dealt with in more detail in sub-section (D) below. The presence of such obstacles is normally to reduce the wind effect at the level of the inlets so that both the leeward and windward pressures would be smaller than those obtained in the model experiments. This is supported by the recorded flows in the horizontal ducts when two inlets were open; high velocities were recorded only when the wind direction was from the north to east quadrant; from the positions of the buildings, and so forth, that form wind obstacles around the block, it is apparent that it is only for winds in these directions that one of the ground-level inlets has a high exposure.

The presence of a thermal contribution to the duct air would not significantly increase the duct air velocity when the opening was windward and exposed to a high wind speed. This thermal contribution would, however, increase the tolerance of the system to an adverse pressure when the opening was leeward. It may be shown that, with a small thermal energy contribution to the duct air, the system would tolerate an adverse pressure of approx. 0·2 velocity head when the wind speed is 20 m.p.h., and approximately 0·1 when the wind speed is 40 m.p.h., i.e., at 20 m.p.h., with a terminal suction of $-0{\cdot}1$ velocity head, the ground level suction could rise to $-0{\cdot}3$ before downflow occurred.

(D) Wind Pressures in a Built-Up Area

The general pattern of the wind flow through a built-up area may be deduced from basic principles supported by general experience. A built-up area may be considered as a composite obstacle with a number of flow paths through it, so that a wind stream incident at the periphery would divide into streams around, through and over the top of the obstacle. Leeward of the obstacle, the streams units again. The velocity of the streams will depend on the flow resistances of the various paths, and on the extent to which the energy is dissipated and is replaced by energy from the upper wind strata.

Ignoring frictional forces, if the velocity along a path falls (e.g., due to an increase in the width of the path), the static pressure P_s is increased and a small upward flow will occur to establish equilibrium between the static pressures at low and high level. Conversely, if the velocity along a path rises, P_s is reduced and there will be a small downward flow. The effect of frictional forces and turbulent eddies is to reduce the magnitude of the velocities along each path. A decrease in the velocity along a particular path, from V_1 to V_2 will cause the stream at velocity V_1 to sub-divide into two streams, one moving along the path at a velocity of V_2 and the other at $(V_1 - V_2)$ out of this path. The oncoming air at velocity V_1 will increase the pressure of the stream of velocity V_2 above that of the upper strata to produce this result and to establish an equilibrium between the static pressures of the flows at low and high level.

The overall general effect of the wind would be to produce streams through and over the obstacle, which may vary considerably in direction and speed, but with only a very small pressure difference between low and high level.

The pressures around the individual obstacles, are superimposed on this general pattern. The published data[11] on experimental studies with models applies for the particular case of wind of uniform velocity and do not take into account the effects of neighbouring obstacles on the high- and low-level flows. Such data apply, therefore, for conditions of maximum exposure. An assessment should be made, however, of the shielding effects of neighbouring obstacles on the pressure distribution around a tall building: for example, where a building is one of a row separated from parallel rows by streets, winds would produce low level flows between the rows, and the high-level flow incident at the upper part of the building may differ in direction and velocity from that at low level. When this is so, the pressure distribution is likely to be very different from that obtained for maximum exposure.

For the exposed case, when the wind is normal to one inlet and the wind speed is approximtely constant throughout the height of the building, the windward and leeward pressures produced are due to the obstruction of the stream by the complete elevation of building. In a built-up area, due to the channelling of the wind stream, the flow near ground level may be parallel to one wall of the building when the upper exposed part is normal to the incident wind. The obstruction to the wind flow is reduced and it seems likely that the pressure produced on the upper part of the windward wall is relieved by the flow in a different direction at ground level. Similarly, on the leeward face, there may be a flow at low level through this area so that, again, the effect of the obstruction of the upper part of the building is relieved. In general, therefore, in a built-up area, the wind pressures at low level are likely to be significantly lower than those obtained from the literature that is currently available.

From these considerations, the observed duct air flows in Figure 7 may be interpreted. It may be deduced from the high horizontal flows observed in the north ground branch when two inlets were open, that, during the high-speed wind period on 28th October, when the south inlet was closed the northerly wind stream would descend from the top of the wing A (Figure 10) and that there would also be flow around the end of this wing. The pressure at the north inlet is, therefore, raised above that of the free wind stream, and the duct air velocity would be somewhat higher than that for a duct with two inlets. During 13th November, when the average wind velocity reached a peak of 40 m.p.h., there was a component of the wind directed into the area north of the wing B so that the pressure at the north inlet would tend to be close to zero. At the same time, winds blowing over the top of this wing would produce a suction effect at the terminal, and the overall wind effect results in an upward flow with a velocity somewhat larger than that present under calm conditions. At the top of the north elevation of wing A, the pressure would probably be negative so that there would be an upward wind flow local to this elevation. It may well be that, at ground level, the wind direction, being greatly influenced by obstacles in its path, differs consider-

ably from that recorded at the meteorological station and measured approximately 80 ft above ground level. It seems likely that this effect may account for the observed performance between 6 a.m. and 9 a.m. on 13th November, when the wind was apparently in a sense to produce a high suction at the open inlet. Similar remarks apply when the north inlet was sealed.

(E) The Effects of Leakage on the Performance of the System

Under calm conditions, it may be shown that the pressure of the air in the duct near the base is below that of the dwellings and this pressure difference decreases with height, becoming zero at about 3 ft from the terminal. Under wind conditions, for a system with two inlets or a neutral area system, the pressure at the base of the duct is zero or slightly negative, and even with a small terminal suction the pressures would be negative throughout the length of the duct. If the dwellings are at a neutral pressure, any leakage flows would be directed into the duct and such flows may be considered as a small additional contribution to the ventilation of the dwellings.

For a single-inlet system, open to windward pressure, the air pressure in the duct would be positive near the base, falling to zero and then to a negative value at higher levels. If the dwellings are at a neutral pressure, therefore, any leakage flows at the lower end of the duct would be outwards.

APPENDIX 5

PERFORMANCE OF THE SE-DUCT SYSTEM: THEORETICAL CONSIDERATIONS

The prediction, from theoretical considerations, of velocities and temperatures induced in a Se-Duct system by operation of appliances only has been published elsewhere.[10] In this appendix, the theory is extended to allow for the flows induced by heat transfer through the walls of the duct, and to enable the combined effects of thermal sources to be calculated. A method is derived for the calculation of the flow rate induced by wind alone and for the combined effects of wind and thermal sources.

The theoretical considerations in each section are used for the further interpretation of the recorded data. Unless stated otherwise, the calculated numerical values apply for ducts with internal dimensions of $9 \times 15\frac{1}{2}$ in.

(A) Flow Due to Thermal Sources Under Calm Conditions

(i) *Heat Transfer Through the Duct Walls*

Assuming, initially, that t_a, t_s and t_w are constant, it may be shown that the duct air temperature t_g is given by

$$(t_w - t_g)_h = (t_w - t_a) \exp(-U_d h/Mc) \quad . \quad . \quad (1)$$

and that the energy per unit mass flow inducing flow is

$$\frac{1}{T_a}\int_0^H (t_g - t_a)\,dh = \frac{H}{T_a}(t_w - t_a) - \frac{1}{T_a}\int_0^H (t_w - t_a)\exp(-U_d h/Mc)\,dh$$

Equating this energy to that dissipated in overcoming flow resistances, equation (2) is obtained, enabling the induced flow to be calculated.

$$H(t_w - t_a)(1 - S)/T_a = M^2(1 + \Sigma R)/2gA^2 d_e^2 \quad . \quad (2)$$

Experimental observations[5] have shown that the duct and its cladding have a high thermal capacity, such that, when the temperature of the duct air changes by t°F in 1 hr, t_w changes by approx. $t/3$°F. Hence, diurnal changes in t_a or t_s do not significantly alter t_w.

Seasonal variations in the mean air temperature alter t_w and, hence, t_g also. By considering the thermal resistances between the air surrounding and the air within the duct, it may be shown that

$$t_w - t_a \simeq 0{\cdot}5\,(t_s - t_a)$$

so that, from equation (1),

$$(t_g)_H = t_a + 0{\cdot}5\,(t_s - t_a)\big(1 - \exp(-U_d H/Mc)\big)$$

In the summer months when $t_s \simeq t_a$, $(t_g)_H \simeq t_a$, and in the winter $(t_g)_H = t_a + 0{\cdot}4\,(t_s - t_a)$. Hence, the variation in $(t_g)_H$, when the air temperature varies from a mean of 60° to 35°F, would be approximately 60° to 40°F, with the diurnal variations superimposed. As M in equation (2) depends on the difference between t_w and t_a, the calculated values of M are equally applicable when $t_w > t_a$ and when $t_w < t_a$; the latter condition corresponds to a downflow.

(ii) *Heat from the Pilot Flames Alone*

When only the pilot jets are alight, the surface temperatures of the appliances remain low and the surface heat losses are small. Hence, almost all the sensible heat from the pilot jets passes into the duct air, by virtue of the flow that occurs through the appliances even when they are not in operation. In addition, following the use of a water heater, an additional 30 B.t.u./hr passes into the duct from the cooling of the heat exchanger.[15]

The values in Table 32 have been calculated on the assumption that the wall temperature is at t_a.

Table 32.—*Predicted Temperatures and Velocities Due to Pilot Jets.*

Heat Input to the Duct Air (B.t.u/hr)	Energy due to Pilot Jet Heat (ft. lb/lb mass flow)	Induced Velocity (ft/sec)	Temperature Rise of Duct Air at Top (°F)
1	2	3	4
200	0·66	2·4	7·1
300	0·87	2·8	9·2
400	1·05	3·1	11·2

(iii) *Combined Pilot Jets and Duct Wall Effect*

The addition of the pilot flame heat to the duct air raises the value of t_g, as calculated from the heat transferred through the wall, and reduces the temperature gradient $(t_s - t_g)$. The effect on $(t_g)_H$ may be deduced by considering the effect of a single pilot flame at a distance h from the top of the duct. The temperature difference $(t_w - t_g)$ due to the duct wall heat up to this level is

$$(t_w - t_a)\exp\big(-U_d(H - h)/Mc\big)$$

and at this level t_g is raised by Q_1/Mc. The temperature gradient, $(t_w - t_g)$ is, therefore, reduced by Q_1/Mc, and, by integration, $(t_g)_H$ is given by

$$(t_g - t_w)_H = (Q_1/Mc)\exp(-U_d h/Mc) + (t_w - t_a)\exp(-U_d H/Mc).$$

The temperature rise is, therefore, equal in magnitude to that due to the duct wall heat alone together with that due to the pilot flame, obtained by assuming the duct wall to be at air temperature. This result applies equally when all the pilots jets are alight. From Table 32, the heat from the pilot jets thus increases $(t_g)_H$ by approximately 9°F in the case of a 10-storey building.

The simplified analysis given above has been based on the assumption that t_w is constant throughout the height of the duct. As shown in (i), $(t_g)_H$ remained almost constant, so that the wall temperature will reach a higher equilibrium value at the top than at the base. When, in addition, the pilot burners are in use, (t_g) again remains almost constant, but at a higher value. Under equilibrium conditions, the

wall temperature at the top is approximately $0{\cdot}7\,(t_g - t_a) + 5 + t_a$ and is higher than that at the base by approximately $0{\cdot}2\,(t_g - t_a) + 5$, i.e., by 5°F during the summer and by 8°F during the winter. The equilibrium value of $(t_g)_H \simeq 0{\cdot}4\,(t_g - t_a) + 10$.

By the same method, it may be shown that the energy-inducing flow is equal to the additive effects of the two sources, where these are calculated for the wall temperatures used in obtaining $(t_g)_H$, i.e.,

$$(t_g)_H = t_w + (t_w - t_a)\exp(-U_dH/Mc) + \frac{Q_1}{Mc}\Sigma\exp(-U_dh/Mc) \quad . \quad (3)$$

and

$$M^2(1 + \Sigma R)/2gA^2d_a^5 = H(t_w - t_a)(1 - S)/T_a + \frac{Q_1}{U_dT_a}\Sigma\left(1 - \exp(-U_dh/Mc)\right) \quad . \quad (4)$$

From equation (4), it follows that the direction of flow will be dependent on the relative magnitudes of the heat sources and whether t_w is greater or less than t_a. When the values are approximately equal and opposite in sense, the flow becomes small and unstable. This instability occurs because when the duct velocity is small the flow is streamlined, and the flow resistance proportional to V rather than V^2. Due to the combined effect of a small flow velocity and small resistance, the flow direction is very sensitive to small extraneous pressures, and low velocity gusts can cause the flow to alternate in direction. The condition in which t_a is greater than t_w occurs when the air temperature rises rapidly; such conditions are frequently accompanied by wind which would offset downflow. In a tall duct, persistent downward flow is unlikely even when pilot jets are not in use, due to the elevation of the wall temperature by heat transferred through the walls. When, in addition, the pilot jets are in use, the possibility of persistent downflow is remote.

(iv) *Appliances in Operation*

If the effect of the appliances being used is superimposed on the pilot burner and duct wall thermal effects, $(t_g)_H$ may be obtained by summing the calculated increments as above.

The new equations for temperatures and energy are

$$(t_g - t_a)_H = (t_w - t_a)\exp(-U_dH/Mc) + \frac{Q_1}{Mc}\overset{n_1}{\Sigma}\exp(-U_dh/Mc) + \frac{Q_2}{Mc}\overset{n_2}{\Sigma}\exp(-U_dh/Mc) \quad . \quad (5)$$

and

$$M^2(1 + \Sigma R)/2gA^2d_a^5 = H(t_w - t_a)(1 - S)/T_a + \frac{1}{U_dT_a}\left(Q_1\overset{n_1}{\Sigma}[1 - \exp(-U_dh/Mc)] + Q_2\overset{n_2}{\Sigma}[1 - \exp(-U_dh/Mc)]\right) \quad . \quad (6)$$

The first summation is for n_1 pilot jets alight, and the second for n_2 appliances at heights h_1, h_2 from the terminal.

The temperatures and energies in Tables 25 and 26 were calculated from these equations.

For a system with one ground inlet, ΣR is increased, the duct velocity and, hence, U_d are reduced. The temperature increment due to the duct wall heat is, therefore, lowered slightly, and those due to the pilot flames and the appliances increased. Hence, closing one ground-level opening produces only a small reduction in the velocity and a correspondingly small increase in the concentration of carbon dioxide.

(B) FLOW UNDER WIND CONDITIONS

(i) *Without Appliances in Use*

The fundamental equation from which the flow rates produced by wind may be calculated is derived in Appendix 4 and is based on the assumption that air is entering one ground inlet only. The conditions for which this is valid may be obtained by considering the limiting condition of zero flow in the leeward branch. When $V_y = V_z$ and $Z = N$ the equation becomes

$$\frac{Z - X}{R_z} = \frac{Y - Z.}{1 + R_y}$$

But $Y > Z$ and, therefore, $Z - X > 0$; hence $Y > Z > X$. With zero suction at the terminal, both Y and Z would, therefore, be positive, a condition that would seem improbable; with $X = -0{\cdot}1$, Z would need to lie between this value and the positive value of Y, again an improbable condition for most values of Y. It follows, therefore, that, for a constant wind speed and direction, air will enter from one or other opening, and, under gusty conditions such that the pressures Y and Z at the openings alternate rapidly, the direction of the flow through the horizontal duct would change rapidly to produce the gusty effect observed.

The velocity V_y produced by the wind is a minimum for the extreme condition $Y = Z$.

(ii) *With Appliances in Use*

The addition of thermal energy to an existing flow induced only by wind, changes the flows through the branches, and, in consequence, the value of N. With the combined effect, the energy producing a flow V_z is

$$(N - X)\,V_w^2/2g + \Sigma E$$

and the value of N may be calculated from equation (7):

$$\left[\left((N - X)\,V_w^2/2g + \Sigma E/0{\cdot}0335\right)/R_z\right]^{\frac{1}{2}} = \left((Y - N)\,V_w^2/(1 + R_y)\right)^{\frac{1}{2}} - \left((N - Z)\,V_w^2/R_z\right)^{\frac{1}{2}} \quad . \quad (7)$$

Whereas, when $\Sigma E = 0$, it has been shown that air enters only through one ground opening, the addition of thermal energy may cause air to enter from both ground-level openings even when there is a suction at one opening.

From the limiting condition $V_z = 0$ (i.e., $Z = N$), values of ΣE given in Table 33 have been calculated for various wind speeds producing various pressure distributions, including the extreme conditions $Y = Z$.

TABLE 33.—*Thermal Energies to Produce Zero Flow in Leeward Limb*

(Ft. lb./lb. mass flow)

		Wind Speed (m.p.h.)				
	X	1	2	4	8	10
$Y = 1$	0	0·091	0·37	1·46	5·85	9·1
$Z = -0{\cdot}5$	−0·1	0·088	0·35	1·41	5·64	8·8
	−0·5	0·075	0·30	1·20	4·78	7·5
	−1·0	0·058	0·23	0·93	3·71	5·8
$Y = 1$	0	0·100	0·40	1·60	6·40	10·0
$Z = -1$	−0·1	0·097	0·39	1·54	6·18	9·7
	−0·5	0·083	0·33	1·33	5·10	8·3
	−1·0	0·066	0·27	1·06	4·25	6·6

From these values, it follows that, for wind velocities up to about 4 m.p.h., air will normally enter through both openings, whilst above 10 m.p.h. air will enter from one inlet only, even when three water heaters are in operation simultaneously. The flow conditions for intermediate wind speeds may take either form. In view of this, either of the predicted values for carbon dioxide in Table 7 may apply, or, indeed, an intermediate value.

Equation (7) enables the influence of adverse pressures to be considered, and, using this, Table 34 has been obtained for the condition $V_x = 0$, thus giving values of the adverse pressure that can be tolerated for various amounts of thermal energy.

TABLE 34.—*Permissible Adverse Pressures*

	Thermal Energy ΣE (ft lb/lb mass flow)	Wind Speed (m.p.h.)					
		5	10	15	20	30	40
$Y = 1{\cdot}0$ $Z = -0{\cdot}5$	0	0·25	0·25	0·25	0·25	0·25	0·25
	1	1·45	0·50	0·38	0·32	0·28	0·27
	7	8·65	2·35	1·17	0·77	0·48	0·38
$Y = 1$ $Z = -1$	0	0	0	0	0	0	0
	1	1·20	0·30	0·13	0·07	0·03	0·02
	7	8·4	2·1	0·92	0·52	0·23	0·13

For a single-inlet system, the adverse pressures that can be tolerated are the same as for the double inlet for the case $Y = 1$, $Z = -1$.

At Gateshead, the suction at the terminal was about $-0{\cdot}1$, and the values in Table 34 would need to be increased by 0·1. Hence, with the basic value of $\Sigma E = 1$, a downflow should not occur for winds below 10 m.p.h. unless a suction of 0·4 was produced at the ground level opening.

(c) INFLUENCE OF GUSTS: WITHOUT THERMAL EFFECTS

When the pressures at the openings to the system change, V_x does not respond immediately, due to the flow resistances and the inertia of the system. At any instant, the value of V_x is given by

$$\frac{dw}{dt} \cdot dt = \frac{m}{g} \cdot \frac{dV_x}{dt} + \frac{(1 + \Sigma R)\, d_a}{2g} \frac{d(V_x)^2\, dt}{dt} \quad . \quad (8)$$

The validity of this equation has been verified by laboratory tests with a duct of 1 sq. ft section and approximately 40 ft in length by subjecting one opening to a suddenly applied wind. For this condition,

$$\tan \mathrm{h}(gt/m)\left(w(1 + \Sigma R)\, d_a/2g\right)^{\frac{1}{2}} = V_x\left((1 + \Sigma R)\, d_a/w\right)^{\frac{1}{2}}$$

It may be shown that in this equation the term arising from the inertia of the air is small and may be ignored, except possibly in the case of large service ducts.

Assuming an instantaneous occurrence of the gust,

$$(w_1 - w_2)\, t = (1 + \Sigma R)\, d_a\, V_x^2/2g$$

where w_1, w_2 are the minimum and maximum velocities of the gust.

When the wind speed is varying rapidly about a mean value, an assessment of its effect may be obtained by considering a sinusoidal variation of a wind of mean velocity V_m varying by $\pm aV_m$ with a frequency of $2\pi/q$. The average effect of the wind itself during one cycle is

$$\frac{Kq\, V_m^2}{2\pi} \int_0^{2\pi/q} (1 + a \sin qt)^2\, dt = KV_w^2 (1 + a^2/2),$$

where K velocity head is the applied pressure difference between the ends of the vertical duct.

It may be shown that when q exceeds a certain value, V_x will follow the average effect and

$$KV_w\, d_a (1 + a^2/2)\, t = (1 + \Sigma R)\, V_x^2.$$

From this analysis, it may be shown that, for Gateshead, high-speed gusts of up to approximately 3 sec duration would influence the flow rate V_x and would produce a larger change in V_x when there is only one ground inlet. High-frequency variations of the wind speed about a mean value have a similar effect to that of the average wind speed.

APPENDIX 6

SYMBOLS

A = Cross-sectional area of flue (sq. ft).
c = Specific heat of air (B.t.u./lb. °F).
d_a = Density of ambient air (lb/cu.ft).
E = Energy (ft lb/lb mass flow).
g = Gravitational constant (ft/sec²).
h = Height variable (ft).
H = Total height of flue (ft).
m = Air contained in system (lb).
M = Mass flow rate (lb/sec).
Q_1 = Sensible heat input to flue from an appliance (B.t.u./sec).
Q_2 = Sensible heat input to flue from pilot jet (B.t.u./sec).
ΣR = Overall resistance factor.
S = $\left(1 - \exp\left(-\, U_d H/Mc\right)\right)(U_d H/Mc)$.
t = Time (hr).
t_a = Ambient air temperature (°F).
t_s = Temperature of air surrounding duct (°F).
t_g = Temperature of air or gases within duct (°F).
t_w = Duct wall temperature (°F).
T_a = Ambient air temperature (°F abs).
U_d = Thermal transmittance value (B.t.u./ft run hr °F).
V_w = Wind velocity (m.p.h.).
w = Wind pressure energy (lb/sq. ft).

APPENDIX 7

LITERATURE REFERENCES

[1] Gas Fire Flues and Ventilation. Masterman, C. A., and Noble, T. G. *Trans. Inst. Gas Eng.*, 1931–32, **81**, 646.

[2] Disposal of Products of Combustion from Gas Appliances. Bennett, A. R., and Reichert, H. *Trans. Inst. Gas. Eng.*, 1954–55, **104**, 259.

[3] Experiments with Common Balanced Flues. Bennett, W. J., and Purkis, C. H. *Trans. Inst. Gas Eng.*, 1953–54, **103**, 460.

[4] Experiments with Shared and Individual Flues for Gas Appliances. Bennett, W. J., and Purkis, C. H. *Inst. Gas Eng. Comm.* 495, Nov., 1956. *Trans. Inst. Gas Eng.*, 1956–57, **106**, 133.

[5] Observations on the Performance of a Multi-flue System and of a Single Duct for Appliances with Room-sealed Combustion Chambers. Carne, J. B., and White, T. T. *Inst. Gas Eng. Comm.* No. 496, Nov. 1956. *Trans. Inst. Gas Eng.*, 1956–57, **106**, 171.

[6] Further Experiments with Shared and Individual Flues for Gas Appliances. Bennett, W. J., Brady, K. J. D., and Dance, E. W. G. *Gas Council Res. Comm. GC*53, Nov., 1958.

[7] The Design and Performance of Natural Flue Terminations and Mechanically Assisted Systems. Wills, D. R., Dance, E. W. G., and Blench, G. T. *Gas Council Res. Comm.* GC61, Nov., 1959.

[8] Investigation of Unconventional Flues. Report to I.G.U. Conference, Rome, 1958.

[9] *Building Research Station Private Communication No.* C377.

[10] Flues for Appliances with Room-sealed Combustion Chambers. Some Theoretical Considerations. White, T. T. *J. Inst. Fuel.*, 30th Dec., 1957.

[11] Wind Loads on Buildings. Schoemaker, R. L., and Wouters, I. *Het Bouwbedrif*, 1932, **22**, 275 to 283.

[12] Design and Performance of Convector Gas Fires. Berry, E. W., and Taylor, J. Paper to London and Southern Junior Gas Association, June, 1960.

[13] A Shielded Hot-wire Anemometer for Low Speeds. Simmons, L. F. G. *J. Sci. Inst.*, 1949, **24**, 407 to 411.

[14] An Introduction to the Theory of Statistics. Yule, G. U., and Kendall, M. G. 14th Edit. (Griffin and Co., Ltd., 1950.)

[15] The Cost of a Domestic Hot Water Service by Gas. Purkis, C. H. Paper to London and Southern Junior Gas Association, Oct., 1949. *Proc. Jun. Gas Assoc.*, 1949–50, **33**, 122.

PRESENTATION, DISCUSSION AND REPLY

Presentation

Mr. T. T. White presented this paper for discussion and summarized its contents.

Discussion

Mr. W. K. Hutchison, C.B.E. (Deputy Chairman, The Gas Council):—I want to begin with a few general observations on the balance of research into the gas industry's effort.

This 26th Autumn Research Meeting has provided an opportunity of listening to two stimulating papers, one by Sir Harold Hartley at the opening session, and the other by Professor M. W. Thring and Dr. C. Hulse, each dealing in its own way with research and development leading to new methods of gas production.

It seems all too easy, when viewing the exciting prospects offered by new advances in the technology of gas production, to lose sight of problems that are likely to have even more immediate significance to the well-being of the gas industry and to its future growth and prosperity.

There are questions surrounding the release of the heat potential of gas. Starting from the highly complex physics and chemistry of the mechanism of flame being studied by Dr. Dixon-Lewis at Leeds, we enter the important field of the combustion characteristics of gas. I need hardly stress how important it is to be able to measure these properties accurately when new processes of gas manufacture are being considered. Finally, there are the more practical aspects of the control of air for combustion, the disposal of air for combustion, the disposal of products, and the design of appliances to meet all the changing demands of industrial and domestic users.

A composite paper has been presented to us; its title indicates its dual nature, and I shall have something to say about this, because these two matters represent quite different approaches to the problem. The paper records a brilliant solution of one of the more urgent problems that have ever faced our industry, and does great credit to all concerned. In view of all that is said from time to time, it is most satisfactory to find an all-British invention being accepted enthusiastically in many countries abroad.

As we know only too well, current conceptions of architecture make no provision for the orthodox chimney system based on the idea that almost every room would have some form of solid-fuel appliance. Architects today are unwilling to provide more than one chimney in a house, and have been reluctant to allow any chimneys at all in their new high blocks of flats. Everything pointed at one time to the virtual elimination of gas from the domestic heating services of the future, just when we came to see that in this field lay our best hopes of expansion.

Looking back, I think we can see that for too long we had been content to base our research and development on ideas derived from the burning of solid fuel, instead of treating the subject as an entirely new one to be solved in terms of the special properties of gas as a fuel.

The first significant advance was the development of a range of appliances based on the principle of the balanced flue, itself a relatively old concept. The elimination of the chimney was an end in itself, but an additional reward came from the increased efficiency that results from control of air injection that balanced-flue operation allows. I sincerely hope that it will not be long before we receive reports of the solution of one major problem outstanding, that of a balanced-flue source of radiant heat.

The special problem of the higher flats could not, however, be solved by these methods alone, for architects are very sensitive to any pattern created in outside surfaces by even the relatively harmless terminal of a balanced flue, and we have now the record of a successful attack on this problem by two quite different methods.

The branched flue represents the outcome of development and improvement, but it remains in principle a traditional chimney adapted to the special requirements of the structure in which it is built and to the mainly traditional types of appliances that it serves. As such, it seems likely to find its principal use in future in conjunction with solid fuel.

The Se-Duct, on the other hand, represents a complete break with tradition and shows how valuable it can be to forge ahead into the unknown, or, rather, into areas where the only knowledge is that gained from theoretical studies. It is very gratifying to observe how fully the observations on installations in operation have verified the theory underlying the design of the flue and the equipment that it serves. This should give the authors and all others concerned with the design of new installations confidence to plan boldly for the future, whatever demands may be put on them by architects and housing authorities.

There remains a gap in the range of appliances necessary for gas to give a full service of heat for every purpose in the modern flat. I hope that manufacturers', as well as our own, laboratories will before long have the answer to the radiant convection fire under balanced-flue conditions, because, however effective our heating systems may be, the public retains an affection for the radiant source that it will be well to recognize.

The authors of this paper can be well satisfied with the outcome of careful and inspired investigation extending over a long period, and they may rest assured of the industry's gratitude for the new opportunities that they have opened up.

I hope that they will not become so deeply immersed in the many day-to-day problems arising from the application of their invention all over the world as to lose the opportunity of directing original thought to problems, many as yet undefined, that will certainly arise if gas is to realize its maximum potential as the fuel of the future.

Mr. W. Sutcliffe (Newcastle-upon-Tyne): As the Northern Gas Board has been closely associated with some of the work described in this paper, and, indeed, has derived considerable benefit from the work of the authors, I welcome this opportunity of paying a tribute to their skill and ingenuity, and of congratulating them on being able to produce such a complete justification of their theories.

Although the wealth of fundamental data contained in the paper will receive careful consideration by experts in their own field, the important fact arising from their work is contained in a small paragraph in the Summary* which reads:—

> "In Section VI, broad conclusions are drawn from the foregoing which may be summarized in the simple statement that theory and prediction have been fully confirmed in practice and some valuable practical lessons have been learned."

I am sure that it is unnecessary to emphasize further the immense importance to our industry of having available two well-proven systems that solve the economic and aesthetic problems of removing the products of combustion from gas appliances.

My own experience has been limited to the Se-Duct system, and in particular to that installed by the Borough of Gateshead in its 10-storey block of flats at Regent Court, operating results of which are given in the Paper.

In 1953, the Borough of Gateshead decided to install gas equipment for space heating, water heating and clothes drying, as well as for cooking and laundering, in four 10-storey blocks comprising 196 flats being constructed at Barns Close. This installation was so successful that the local authority decided to repeat it in its proposed 10-storey block of 160 flats at Regent Court. The architectural features of this block, however, varied in detail from those at Barns Close, and it soon became apparent that the normal balanced-flue system previously adopted for the multi-point water heaters was not acceptable. By a fortunate combination of circumstances, the Se-Duct system was at that time in its final development stage, and offered an immediate solution to the problem. After careful consideration the Se-Duct was accepted by the Corporation, and the design of the flats modified to allow it to be incorporated, a

* See I.G.E. Journal Vol. 1, No. 1, p. 46.

decision that called for considerable courage on the part of the Corporation's officials and the local Housing Committee.

The results now published provide scientific evidence that their courage was justified. This is a source of considerable satisfaction to them, as it must be to the authors and others who have since adopted these systems.

Since the Regent Court flats were occupied in November, 1958, they have been visited by many officers of local authorities and by private architects, and, from my own observations, these visitors have been impressed by the neatness of the system, both inside and outside, and by the tenants' obvious satisfaction with the installation and running costs. Even before the work described in the paper was concluded, it was apparent that the system was successful; indeed, on Tyneside alone 13 blocks of 12 or 15 storeys, comprising 1,070 dwellings, and 207 dwellings in three- or four-storey blocks, are currently under construction by local authorities or private builders, and are scheduled to be completed in 1961 or 1962, and all incorporate Se-Ducts.

It is encouraging to note that the authors are satisfied that single inlet ducts can be used in a large proportion of buildings and that the number of appliances fitted to each duct can be increased. This will in large measure obviate the difficult problems that have been met in fitting in the horizontal ducts, will facilitate the internal planning of the building, and make the system even more acceptable from æsthetic and financial points of view.

During the erection of these flats, it has been apparent that the contractor's problems associated with the construction of the main flue itself, and the making of the holes for the appliance flues, have been overcome, and the methods illustrated in Figures 17 and 18 of the paper have proved to be particularly suitable. There is, however, room for improvement in the design of the appliances to make it easier to present a neat appearance on completion. I understand that this point is receiving the attention of the appliance makers.

The increased number of appliances available for use with the Se-Duct is welcomed, and one looks forward in particular to the speedy fulfilment of the promise that a gas fire will be added to the list in the near future.

The value of the work done by the authors and their colleagues on flue systems over the past years cannot be overestimated or over-emphasized, and this latest paper proves beyond doubt that their systems are sound and practical propositions.

Whilst this work has added much to our knowledge of the factors influencing the design and operation of flues, and as such is of great value, the true value to the gas industry will not be realized until the commercial potential of the author's work is exploited to the full. I hope that this will take place with the same speed and sense of urgency.

Mr. H. G. Hammond (London):—It seems to me that the work and research that have gone into developing flues of the character of the branched flue and the Se-Duct arises from the tendency in post-war housing to build tall buildings, which in turn derive from the need or the desire to improve amenity in housing areas by creating open space where it might otherwise have been occupied by single-storeyed or double-storeyed buildings.

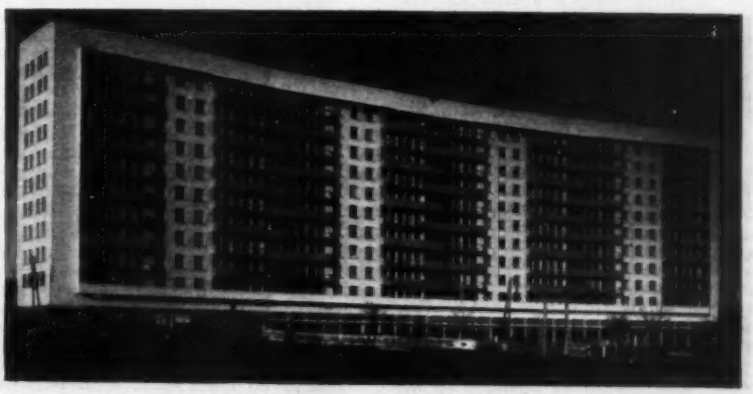
The development of tall buildings of 12 or 20 storeys, or even more, leads to all sorts of new problems, one of which is the accumulation of flues in the centre of the building. The difficulty of providing flues for solid-fuel appliances—coal-burning appliances—and the difficulties of transporting solid fuel to various floor levels of a building, have practically eliminated solid-fuel appliances from modern blocks of dwellings.

I can say, to the satisfaction of all those who have worked in this field, that both the branched flue and the Se-Duct have removed all embarrassment in the planning of flats within the very tight limits on floor area and costs that control housing, especially in tall blocks. This must be a source of satisfaction to all concerned.

I have had some experience of planning tall buildings, and the size of the Se-Duct, in particular, is an excellent solution to the problem of providing heat for space heating, for water heating and for clothes drying. The amount of space that it takes up is so small as not to be in any way embarrassing in the planning of State-aided housing.

There is only one other matter I should like to mention: tall buildings produce very noticeable skylines, and local authorities and architects are very sensitive to the skylines of buildings. The difficulty of keeping terminals out of sight or so placing them that they are inconspicuous or are æsthetically satisfying is perhaps the most serious consideration of the architect in using flues of this type. I notice that the Se-Duct is easier to accommodate in this respect, since it is not so prone to down draughts arising from buildings at roof level. I do not know whether anything more can be done in this sphere. I know that it has been successfully overcome in some buildings, and I feel that it would be helpful if more data were available to architects on the precise positioning of terminals and on the optimum positions for terminals in relation to ducts and to parapet walls, roof buildings, and the like.

Monsieur P. Richalet (Paris, France):—The company that I represent was formed specifically for the utilization of the Se-Duct and the use of appliances for connecting to it. The first block that we put up, using the Se-Duct, in France comprised 160 flats, 10 storeys high, with two generators of 100,000 B.t.u./hr output each.



A block of 160 local-authority flats at Cholet, France. There are eight No. 4 size Se-Ducts, with two generators per floor on each, providing space heating and water heating.

I am in complete agreement with the authors as regards the section of the Se-Ducts, and we have proved to our satisfaction that this can be reduced by 30 per cent to 40 per cent. I am also in complete agreement with them as to the possibility of eliminating the horizontal duct in all cases where there is sufficient air at the base of the duct. On the other hand, I am convinced of the importance and, indeed, necessity of providing free access of air at the entrance to the duct so that any down-pressure effects may be avoided.

In the six months, we have studied 20 large blocks where about 2,000 appliances have been installed. The last one studied contained 200 appliances.

French architects are extremely interested in the Se-Duct, especially in the placing of the duct in the middle of the building. Among other appliances especially suitable for use with the Se-Duct is the drying-cabinet.

I should like to congratulate the authors on a very interesting paper and for the tremendous amount of work done by them. I should like, also, to thank them for the facilities that they have extended to me on my visits to Britain.

Mr. N. Barnes (London):—This paper deals with the later development stage of the projects concerned, and is so informative as to leave little to question. I should like to take the opportunity of making some broad remarks, from the appliance manufacturers' point of view, on the handling of such projects, with particular reference to instantaneous water heaters, with which I have been most concerned.

The work involved in developing and proving the design of tall flues is such that it could not be expeditiously undertaken by manufacturers. It is, therefore, most important, and much appreciated, that The Gas Council should carry out work of this nature. In some cases, such as branched flues, the problem may be solved with little impact on the appliances. In other cases, such as the Se-Duct, the appliance design is affected and the manufacturer can make a contribution to the development.

In the latter case, the method of working between The Gas Council and manufacturers is interesting in comparison, for example, with its equivalent in America. In both countries, the gas authority conducts research work and gives appliance approval, but in America there is nothing in between; the authority and the appliance manufacturers do not collaborate in the development of particular projects. This could create difficulties, but in Britain we cheerfully assume that these can be overcome, and the result is a live combination from which many successful developments have emerged.

All developments involve a step into the unknown, and some must be taken outside the laboratories and subjected to practical operation before the design principles are fully understood. This is instanced by the four points quoted in the paper, namely, the effect of extrapolation, of practical construction, of weather conditions, and of usage. If this problem is approached with undue temerity, development stagnates, but in accepting the risks involved by more rapid development the manufacturers appreciate very much the responsibility shouldered by The Gas Council, which approves the appliances and vouches for the installation during the initial practical stage. This is well illustrated in the case of the Se-Duct, and also the previous related work on balanced-flue appliances. The willingness to venture was demonstrated when our friends in France decided to erect their first Se-Duct installation, mentioning that it had to be adapted to natural gas. I should like to say how pleased I am that Monsieur Richalet has joined in this discussion.

The risks I have mentioned are covered in the initial practical installation by adopting generous safety factors, and a vital process in development is the confirmation of theory in the light of practical data and the reduction of safety factors where possible. It is a great tribute to the quality of work on the projects described that all such factors have been confirmed or reduced, as in the cases of appliance usage, duct dimensions and simplified inlets.

In some cases, a greater advance can be ventured in the practical installation if it is possible to provide a proved alternative. This was instanced in the West Ham branched-flue installation when normal flues were built-in for use should the experimental flues prove unsatisfactory.

What of the future? The work done so far will enable increasingly economic installations to be made, and I am pleased to note the further work suggested. This will not merely permit installations of the current form to be further simplified, but will ensure the best foundation for further developments, which will undoubtedly come, for instance, on appliance design, duct construction and building layout.

It is clear from my remarks that I believe the work described so explicitly in the paper to be most important, and I should like to congratulate the authors accordingly.

Mr. P. Crawford Sugg (London):—I propose to confine myself to some of the points in design of warm-air heaters for use on the Se-Duct. When Mr. G. H. Fuidge and his colleagues, Mr. Carne and Mr. White, first discussed with me the desirability of producing a selective warm-air heater for this purpose, I was already experienced in the design and construction of conventionally flued heaters. This dated from the introduction of the free-standing "Halcyon" heaters shortly after the Second World War, and included that gained in some years of house trials during the development of ducted heaters and the selective air heating principle.

The then existing conventionally flued heater had an input of 0·23 therms/hr and an output of 17,000 B.t.u./hr. In dwellings of average construction, this, used selectively, ensured a satisfactory heating result with living-rooms of a volume up to 2,500 cu. ft, i.e., say 20 ft × 15 ft × 8 ft. However, the economy of operation possible with the selective system had proved such that it was decided, in building the final model of the room-sealed heater for the Se-Duct, to increase the gas input to 0·3 therm/hr and thus to raise the volume limit for the living-room to 3,250 cu. ft. This would correspond to a heat input of 6·8 B.t.u./cu. ft of space and would deal with the heating of many open-planned dwellings.

The opportunity was also taken to incorporate a number of features that were novel at that time, and the result was a heater similar to that illustrated in Figure 16 of the paper, but excluding the water circulator. The use of interchangeable circular drums for both the combustion chamber and the flue manifold presented advantages in manufacture to the necessary degree of sealing and continued the use of materials that years of district experience had verified as having a satisfactory life. The advantage of application of this heat exchanger, which is situated diagonally in the heater body, was that air could be passed through it in any desired direction. The heater could, therefore, be arranged in relation to its fan in the most suitable way for connexion to the associated duct work.

In fact, in the "Halcyon" room-sealed heater, the counter-flow arrangement with fan on top and air outlet below has been universally used to date with the object of standardizing practice and simplifying the task of the various trades involved in installing the equipment. Such an arrangement is equally suitable for dwellings built to either hand. A somewhat larger volute and rotor for the fan than that used on the earlier heater provided the necessary increase in air flow and permitted the use of a modest length of underfloor duct. The cross-section of these ducts, 12 in. × 6 in., enabled the use of a fan motor of only 1/80th h.p. This, with vibration insulation technique and acoustic lining to the heater body, ensured an acceptably low noise level.

The construction of the fan as a separate lift-off unit, including all the electrical equipment of the heater, provided facilities for easy servicing and permitted the insertion of further vibration-absorbing material below this unit.

It may be of interest that the heat exchange tubes are secured without the use of welding so that all parts of the heat exchanger have a limited freedom to expand or contract with change of temperature. This is essential in an appliance which, under room thermostat control, may start and stop several times in each hour. The heat exchange tubes are of chromium-diffused mild steel and are controlled in length to within three or four thoustandths of an inch. They are clamped between the flat machined faces of slotted iron castings saddled to the cylindrical drum. The tubes are located on the casting by spigots pressed in thin metal gaskets, the gasket at the hot drum being of stainless steel and that at the cold drum of copper and asbestos. The clamping rods securing the whole are spring-loaded at the cold end only.

Such a heat exchanger, in which the length of travel of the gases from each burner flame to the exhaust drum is equal, can readily be designed for a predictable temperature pattern and thus freed from condensation problems.

The degree of sealing achieved by this construction was sufficient to withstand the ¼ in. w.g. pressure leakage test specified in B.S.1250 for balanced-flue heaters. Thus, the one design of heater with suitable flue adaptations could be used, not only on the Se-Duct, but also with conventional flue or balanced flue, a feature of considerable value in production and application.

The latest version of this heater shown in Figure 16 has recently been approved by The Gas Council. It incorporates the same form of heat exchanger and fan, but has, in addition, a room-sealed chamber at the front in which a water circulator such as the "Circulyn C.28" may be optionally installed on the site. The two appliances are completely independent as to use and control, but have common gas and flue connexions.

May I say with what feelings of admiration I have studied the monumental work involved in the paper before us. This work has indeed revolutionized the prospects of the industry in the domestic space heating field, which were previously limited to buildings of modest height.

Monsieur R. Liard (Gaz de France):—I should like to say how greatly we are interested in France in branched flues and Se-Ducts. Branched flues have become in France an ordinary way of venting appliances, but with some restrictive conditions that this paper may help us to enlarge.

A certain number of blocks including Se-Ducts are under construction or are projected in France. In some cases, such blocks are occupied, as Monsieur Richalet has said. In the North of France, there is a project of 19 storeys, which includes six ducts. The construction of Se-Duct now requires a special waiver of the regulations, which the public authorities give only for experimental purposes. This will be the case until a sufficient amount of results are available. I am sure that the present paper and discussion will be helpful in this respect.

An experimental installation was built at the Research Centre of Gaz de France and is used also for demonstration purposes. Observation at the installations on the district has just started, and only a few results are as yet available.

We are receiving more and more inquiries about Se-Duct, and many architects are interested in it. There is no doubt that the work of the South Eastern Gas Board is bringing a very valuable development to the use of gas appliances, not only in Britain, but in France and in many other countries.

Mr. L. F. Daws (Building Research Station):—I should like to congratulate the authors on the high standard of their paper. It is very clear that to a large extent they have shown that these complex processes behave in practice as predicted. This is more true of the Se-Duct system, where adverse wind effects have been largely eliminated and where the performance of the system is therefore more under the control of the designer than is the branched-flue system, except possibly for the acoustical effects that the authors mention in Section IV(5)(c). I have been rather amused by some of these.

In the case of branched flues, the authors say, in Section III(1)* that these must be treated statistically from the design point of view, and an economic choice made. While agreeing with this, I am wary of the recommended design value of 0·005 in. w.g. to ensure up-draught, particularly at the top of the system. From the frequency of occurrence of various pressure drops across the appliance, shown in Table 2, the conclusion could be drawn that the incidence of down-draught would have been greatly increased if the terminal effect were slightly more adverse, or if the stack pressures were slightly lower.

This raises the question of the stability of operation at the top of the system discussed by the Authors in Section III(4). I feel that a recommended design pressure drop of 0·005 in. w.g. may not be enough to ensure stability, since the pressure losses in the rest of the circuit would be of the same order. While the authors say it may be unnecessary to vary the resistance of appliances with height in the system, I should like to suggest it might be worth while using a smaller subsidiary duct at the top of the system. This would have the effect of increasing the thermal resistance and so raising the driving force in that part of the circuit, and at the same time one would be able to increase the resistance of the appliances at this height to give the same performance. In this way, one might be able to achieve a more stable situation.

There is one other thought on the subject of branched flues: I wonder whether the authors had any experience of the use of draught stabilizers, particularly at the top of these buildings, in order to control the air inlet into the vicinity of the appliance.

* See I.G.E. Journal Vol. 1, No. 1, p. 48.

Written Contribution

Mr. D. R. Wills (London) wrote:—This paper is a further contribution to the better understanding of one of the more troublesome problems on the utilization side of the gas industry, namely, the disposal of the products of combustion. It is one of a sequence of papers, and I think the first one, drawing attention to the possibility of unconventional systems, was that on common balanced flues published in 1953.

This type of paper illustrates clearly the interdependence and inter-relationship between laboratory work and field experience, or field research. It may be asked: Why is it necessary to continue the instrumentation of actual installations, when the first one or two seemed to confirm, fairly closely, the laboratory findings? I have, in fact, heard the view expressed that some of the work, after the instrumentation of an early example of an unconventional flue system, may largely be superfluous. This is assuredly short-sighted, because experience revealed by the other examples of careful instrumentation and careful measurement has shown each to possess some individuality of its own. It would be foolish, even at this stage, to say that we know all we should like to know about the behaviour of unconventional flue systems, because there are so many factors involved.

In all extrapolation from laboratory findings, there is always a small amount of anxiety because of the possibility of some factor, or some phenomenon occurring, which was not foreseen at the laboratory stage; or even after one or two practical installations have proved more or less successful. One factor, for example, of which little was known, was the diversity of use, and in nearly all design work, particularly in the provision of services, this factor is overwhelmingly important. A better knowledge of the diversity factor permits a much more economical design, and the results in this paper suggest clearly that there is a strong possibility that the sizes of some of these unconventional flue systems can be reduced, with a subsequent saving in space and, perhaps, cost.

Other problems that have arisen, which were not foreseen at the laboratory stage, have been concerned with noise, the ignition of appliances, the stability of pilots, occasional delayed ignition, and so on. Even at this stage, I am not convinced that we have gone far enough in the design of appliances for Se-Duct operation in the direction of easing the problems of ignition, control, *etc.* On this whole question of field research to confirm laboratory predictions, the policy is an extremely sound one and has not been better illustrated than in the present instance. I hope that, in spite of the urgency of some of the problems and the necessity to develop more and more ways of using gas, we on the research side will be permitted to continue field research of this type and be given opportunities to sit back and think, and, occasionally, just to sit back! At the moment, it would seem that we have been able to tackle the problems of flats up to 16 and 20 storeys high, but we are now asked to consider flats of 30 and 40 storeys high, and it may well be that these will present problems very different from those so far experienced. The range of results obtained from the field tests have made it possible to set up a laboratory installation in which all the variants can be independently controlled, and I am sure this will lead to a more rapid development of Se-Duct appliances.

Another part of this paper describes the work on models, with particular reference to the importance of position of the terminations of some of the unconventional flue systems. Here again, it illustrates the tremendous help that can be given to the laboratory scientist by being able to make full-scale measurements under natural conditions. If a model technique

can be established and the results of such work can be applied with some confidence it makes it possible to perform quite economical tests and offer predictions that may often subsequently save a considerable amount of money and trouble. In one instance, it was possible for us to make a considerable number of measurements on a branched-flue system in a block of flats prior to occupation. These measurements revealed that some trouble might be experienced at certain levels, because of the extension, for decorative purposes, of a canopy built on to the tank-room on the roof of the block of flats. The existence of this canopy altered completely the pattern of pressure decay away from the wall of the tank-room. It was clear that this could interfere with the performance of two of the branched flues. Models of different scale were set up in the laboratory, and tests were made over a wider range of conditions that included free exposure of the building and eventually led to the concept of an infinite roof plane. From these scale tests, it was possible to set up conditions by which a completely similar set of pressure records could be obtained compared with the full-scale effects. We know there are many people who are always suspicious of model techniques, and, indeed, it is one aspect of research in the laboratory that needs careful handling, the results from which need careful interpretation. We feel, however, that with the experience so far gained it is possible to predict reasonably accurately the likely performance of flue systems, as affected by terminal design and position. It may be that I am labouring this interdependence of field experience and laboratory research a little heavily; I do so because it has often saved us from embarrassment and I have yet to know of a case where it has not paid off.

It has given me great personal pleasure that there has been such a combination of forces in preparing and presenting this very valuable paper.

Written Reply

The **Authors,** in reply, wrote:—The Authors are grateful to Mr. W. K. Hutchison for such a stimulating opening to the discussion of their paper, and there is only one point on which they wish to comment. From the experience given in the paper, there would seem to be a considerable potential for the branched-flue system for gas appliances as well as for solid fuel. The essential difference between the design of flues for gas and solid-fuel appliances is that the performance of a gas flue is more readily predicted by virtue of the constant heat input to it and the relatively controlled flow conditions encountered. As a result, the sizing of gas flues can be a precise calculation, and the excessive overload margins necessary for solid-flues are no longer needed. This is especially true in the case of shared flues, and whereas the solid-fuel branched flue is limited to three open fires or about five closed stoves, there is no reason why 10 or more gas appliances should not be connected to a single main stack. Indeed, an installation under construction in London at the present time incorporates 16 appliances into an 8 in. by 12 in. main flue.

It was interesting to hear from Mr. W. Sutcliffe of the background to the installation at Gateshead. The Regent Court block with its 16 Se-Ducts has provided a tremendous impetus to the establishment of the Se-Duct as a sound venting system, and the Authors are indebted to the Northern Gas Board for being forerunners in this field.

It is hoped that all architects will agree with Mr. H. G. Hammond that no difficulty is experienced in incorporating shared flues in the design of tall buildings: the authors have sometimes felt that no flue is small enough for some architects. There is no doubt, however, that, if the flue is introduced into the design at an early stage, the problems associated with its incorporation are minimized. Mr. Hammond is correct in observing that the termination is less critical in the case of the Se-Duct than with the branched flue, and this is an inherent feature of the system. It should be mentioned, however, that one enterprising architect on the Continent was so impressed with the appearance of the "Shunt" terminal that he made it a feature of his roof design by installing dummy terminals in a symmetrical pattern.

It is always a pleasure to hear from friends in France and the authors are gratified to learn from Monsieur P. Richalet and Monsieur R. Liard of the complete satisfaction encountered there with the use of the Se-Duct. The reduction in duct size that they have achieved confirms the Authors' own findings in this respect. The Authors are gratified also to read the recent report of Gaz de France on its studies of the branched-flue system as carried out at Gennevilliers.

Both Mr. N. Barnes and Mr. Crawford Sugg have referred to the paper from the manufacturers' angle, and their experiences and observations are most interesting.

Mr. L. F. Daws makes a number of technical comments on the paper. The figure of 0·005 in. w.g. updraught, which he queries, represents a pressure drop across the appliance sufficient to ensure substantial, if not complete, clearance of the products of combustion. The value chosen was obtained from the pressure-against-flow characteristics of the fire. The Authors agree that a greater proportion of downdraught would be experienced if the terminal effect were less advantageous, but, as has been pointed out in this paper, the termination is probably the key to the successful operation of a branched-flue system.

Gas appliances used with branched-flue systems can be divided into two classes:

(ii) Appliances fitted with draught diverters (e.g., water heaters and air heaters), which produce a controlled flow through the appliance.

(ii) Appliances such as gas fires, which have a flue break, but which depend on the appliance resistance for a controlled flow.

In case (i), the optimum performance can be obtained by the use of thermally operated flue dampers fitted in the draught diverter, which tend to control the flow up the subsidiary flue. In case (ii), the control depends on the degree of restriction. This resistance will normally be somewhat greater than 0·005 in. w.g., since this figure represents substantial clearance only, whereas normal conditions require a pressure corresponding to complete clearance plus an additional ventilating flow. Under these conditions, with a tall flue and a limited number of appliances concentrated on the lower part of the flue, the appliance resistances will predominate and a fixed restriction may be possible. Under less favourable conditions, an adjustable restriction may be necessary.

In the Authors' experience, no use has been made of draught stabilizers, although thermally operated flue dampers are being used on new installations involving water heaters.

The Authors welcome the support from Mr. D. R. Wills for the continued investigation of district schemes of unconventional flues. More work remains to be done in this field, particularly in connexion with mechanical extract systems, which, although outside the scope of the present paper, are a natural extension of the work.

Finally, the Authors would like to thank all those who have contributed to the discussion for the many interesting points raised.

Proceedings of Council

The following matters of general interest were among those dealt with by the Council :—

COUNCIL MEETING, 31st JANUARY, 1961

It was reported that Mr. J. D. Grant, M.A., had resigned as a District Member of Council, consequent upon his resignation from the Chairmanship of the British Junior Gas Associations' Joint Council, and that Mr. T. W. Pickthall, the new Chairman of the Joint Council, will succeed Mr. Grant as District Member of the Institution Council.

Reports were received of meetings of the following Committees of the Institution :—

(1) PUBLICATIONS COMMITTEE, on 6th December and 11th January

The Committee had carefully scrutinized the first issue of the Institution *Journal* and had agreed certain editorial improvements for the second issue.

(2) LIBRARY COMMITTEE, on 25th January

(*a*) The Committee had considered a list of new books on gas and related subjects, and had agreed those to be purchased for the Library.

(*b*) The Council approved the recommendation of the Committee that, after the 98th Annual General Meeting, the Library Committee should be merged with the Publications Committee.

(3) METERS COMMITTEE, on 14th December

The Council noted the progress of the work of the Sub-Committee on Meter Performance and the Sub-Committee on Standardization of Small-case Meters and of the investigation by Area Boards of the performance of industrial meters at overload rates.

(4) GAS DISTRIBUTION COMMITTEE, on 26th January

Matters considered by the Committee had included devices for indicating when a gasholder has blown, mains and services surveys, copper service pipes and plastic service pipes.

(5) COMMITTEE ON UNACCOUNTED-FOR GAS, on 13th December, 1960

Particular consideration had been given to leakage from gasholders and to the temperature of gas measured in domestic and industrial meters.

(6) GAS EDUCATION COMMITTEE, on 25th January

(*a*) The Council approved the recommendation that, after July, 1961, the Board of Examiners be reconstituted to comprise four panels each of three examiners to deal with, respectively, Gas Engineering (General Paper), Gas Engineering (Manufacture), Gas Engineering (Distribution) and Gas Engineering (Utilization). The membership of the four panels was agreed.

(*b*) The recomendation that a short course for teachers of gas technology be held in July, 1961, was approved.

(*c*) A report was received of the arrangements for the short residential course for gas distribution engineers, to be held at Oxford from 9th to 15th April, 1961.

It was reported that Mr. A. G. Palmer, M.B.E., B.Sc., had accepted the Council's invitation to succeed Mr. T. C. Battersby, M.B.E., as Chairman of the Gas Works Safety Rules Committee.

It was reported that Mr. G. E. Currier, O.B.E., had been elected Chairman of the Mechanical Engineering Advisory Committee of the Bradford Institute of Technology.

A report was made of a successful joint meeting of the London and Southern and the Eastern Sections of the Institution, on 30th January, at which a paper, " Current Developments in the Gas Industry in France ", by Monsieur R. Odier (Gaz de France), had been presented, with a supporting film, and discussed.

The following were appointed to represent The Institution of Gas Engineers upon technical Committees of the British Standards Institution :—

(*a*) Mr. C. Lewis and Mr. L. J. Mountjoy on Committee GSE/11 (Carbonization and Gasification Test Plant Code).

(*b*) Mr. W. T. Gedge on Committees STB 2/1 (Concrete Aggregates) and CEB 6/1 (Concrete Blocks and Bricks).

Membership Register

Every member of the Institution received, with his copy of the *Bulletin* for November, 1960, a membership register card and a business reply envelope. Most members have complied with the request for the card to be completed and returned to the Secretary, thus ensuring that the information contained in the membership register of the Institution is as complete and up-to-date as possible.

Members who have not yet returned their membership register card are particularly requested to do so without delay. If they have mislaid the card and envelope sent to them, they are requested to obtain replacements from the Secretary of the Institution.

Binding of Journal

Arrangements are being made with a firm of bookbinders to enable subscribers' copies of the issues forming Volume 1 of the *Journal* to be bound at the end of 1961. It is intended that the bound volume will match the binding of the *Transactions*, publication of which has been superseded by the *Journal*.

Full details will be announced later, but, in the meantime, subscribers who wish to take advantage of this facility are advised to preserve their copies carefully.

Christmas Lecture for Young People

In addition to the Christmas Lectures for Young People reported in the February issue of this *Journal* (Vol. 1, pp. 135 to 138), the following lecture was given in the Midlands:—

Birmingham and Derby

Under the auspices of the Midland Section of The Institution of Gas Engineers, Mr. J. E. Cooper, B.Sc. (Technical Officer (Utilization), East Midlands Gas Board), delivered a lecture, entitled "Flame", on two occasions in January.

On Friday, 13th January, 1961, in the Matthew Boulton Technical College, Birmingham, Mr. Cooper addressed an attentive audience of 500 fifth- and sixth-form pupils from Birmingham schools. Mr. S. K. Hawthorn (Chairman Midland Section) introduced the lecturer and welcomed Mr. H. S. Cheetham (President of The Institution of Gas Engineers) and Mr. E. H. Harman (Deputy Chairman, East Midlands Gas Board). Mr. E. J. Machin (Inspector of Schools, City of Birmingham Education Department) proposed a vote of thanks.

On Wednesday, 18th January 1961, Mr. Cooper repeated his lecture in the Mackworth Secondary Modern School, Derby, to some 300 young people from local secondary schools. Mr. F. Harvey (Vice-Chairman, Midland Section) took the Chair, and Mr. R. S. Johnson, M.B.E., M.A., LL.B. (Chairman, East Midlands Gas Board), and Mr. W. R. Branson, M.Sc. (Deputy Chairman, West Midlands Gas Board), were also present.

In proposing a vote of thanks to the lecturer, Mr. J. Gresham Taylor (Deputy Director of Education, Derby) expressed a hope that this first Derby lecture would be followed by others.

Christmas Lecture: Mr. J. E. Cooper, B.Sc., in the Midlands

Short Course for Teachers of Gas Technology

A short residential course for teachers of Gas Technology will be held at the School of Agriculture, Houghall, Durham, from 16th to 22nd July, 1961.

The course, which will be under the direction of Mr. F. Caunce, H.M.I., assisted by other H.M. Inspectors, will be devoted mainly to the consideration of teaching methods and techniques, with particular reference to the teaching of Gas Technology.

Accommodation

By arrangement with The Institution of Gas Engineers, all teachers accepted for the course will be accommodated, free of charge, at the School of Agriculture, for the period from dinner on the evening of Sunday, 16th July, to breakfast on Saturday, 22nd July. It is expected that all the teachers attending the course will "live-in", but, if exceptional circumstances make this impossible, special mention must be made of the reason on the application form.

Tuition

No fee will be charged for tuition.

Travel

Subject to regular attendance and compliance with the rules for the course, the Ministry of Education will assist towards travelling expenses necessarily incurred in attending the course by teachers in grant-aided service and in schools recognized as efficient. The amount of assistance will, in general, be limited to second-class rail fare by the cheapest route, less 10*s*. Full particulars will be notified to selected students.

The Institution of Gas Engineers is prepared to reimburse teachers approved by the Ministry of Education at this course, by refunding the balance of 10*s*. travelling expenses not paid by the Ministry.

The attention of candidates wishing to apply to their local education authorities for financial assistance for expenses incurred in attending the course is drawn to the need to make themselves fully acquainted with their authorities' regulations and procedure in this respect.

The demand for places at the Ministry's courses usually greatly exceeds the accommodation available. Applicants should be reasonably sure that, apart from unforeseen circumstances, they will be able to attend if selected. The Ministry will notify all applicants whether or not they can be admitted.

Applicants selected must be prepared to attend throughout the course and to comply with the rules made to ensure the satisfactory conduct of the course.

Forms of application for admission (Form 106 R.S.C.) are obtainable from local education authorities. Completed forms should reach the Ministry in accordance with the directions on the form, *as soon as possible and in any case not later than 30th April*, 1961.

Joint Meeting

A joint meeting of members of The Institution of Chemical Engineers and The Institution of Gas Engineers will be held at The Royal Institution, 21, Albemarle Street, London, W.1, on Wednesday, 22nd March, 1961, at 2.30 p.m. A discussion on "Some Factors in the Safe Operation of Air Separation Plants" will be introduced by Dr. J. B. Gardner, A.R.C.S., D.I.C., F.R.I.C., M.I.Chem.E.

Translations of Foreign Papers

The following translations of foreign articles have been added to the Library of the Institution since the issue of a list in the September, 1959, issue of the Institution *Bulletin* and are available for consultation or loan:—

Dommer, Otto. Modern Techniques in Instrumentation for Gas Production, Distribution and Utilization. (*Gaswärme*, No. 4, 1957, pp. 132 to 139.)

Foch, Pierre, and Busso, Raoul. Selection of the Retention Period of a Coke Oven Charge. (A.T.G. Congress, 1959.)

Janák, Jaroslav, and Matousek, Ladislav. Colorimetric Determination of Resorcinol in Industrial Waste Waters and Phenolic Products. (*Chem. Listy.*, 1954, **48**, 1176 to 1180.)

Janssen, *Jr.* H. Bellows-type and Valve-type Gas Meters. (*Gaswärme*, **9**, February/March, 1960.)

Jordi, F. A Year's Experience with Gas Depoisoning. (*Monatsbulletin*, November, 1959, **39**, 251.)

Sordelli, D. Precision Equipment for the Preparation of Calibrated Gaseous Mixtures. (*La Rivista dei Combustibili*, February, 1959, pp. 122 to 135.)

Soulet, Jean, and Tournon, André. Construction of an Overhead Grid in Brazed Aluminium Alloy for Distributing Gas Under Medium Pressure. (A.T.G. Congress, 1960.)

Through its membership of A.S.L.I.B. (Association of Special Libraries and Information Bureaux), the Institution has access to the Commonwealth Index of Unpublished Scientific Translations. This index is maintained by A.S.L.I.B. for the use of its members and records the existence of translations and their location. In addition, the Institution is able to obtain translations on loan from the National Lending Library for Science and Technology. The loan collection at the National Lending Library includes translations of Russian and Chinese articles, Russian books and cover-to-cover translations of Russian periodicals.

Further information on these facilities can be obtained from the Secretary of the Institution.

Institution Register

Transfers

To Membership:

Blakeley, William Firth	Leeds
Craven, Derek	Cardiff
Fitzsimons, Walter Anthony, B.Sc.	Cheshunt
Gray, Charles Frederick Richard	Twickenham
Moule, Ernest Stephen	Stoke-on-Trent
Parnall, William Morris Kerkin	London
Shaw, Harold Paul	Orpington

To Associate Membership:

Rummey, Maurice Walter Percy	Southampton
Scarth, Anthony Percival	Brentwood
Sibbald, David Webster	Kirkcaldy

Admissions to Studentship

Anderson, Brian Harold	Darlington
Ball, Norman Percy	Potters Bar
Barber, Alan Edward	King's Lynn
Barron, John Robert	Whitley Bay
Chamberlain, Clive Terence	Barnsley
Champness, Alan Raymond	Sutton Coldfield
Church, Barrie John	Waltham Cross
Disbrey, Ivor John Wallace	Barton
Elliott, William Moore	Belfast
Findlay, James William	Newcastle-upon-Tyne
Harrison, Norman	Stoke-on-Trent
Holbeck, Charles John	Blackburn
Malik, Omar Din	Birmingham
Markham, Alan Terence	West Bromwich
Martin, Peter	Middlesbrough
Mead, Gregory Alan	Derby
Schofield, Gordon	Morecambe
Sharp, William Richard	Northampton
Whinnie, Peter	Blyth
Woollard, John Barrington	Watford

Deaths

The Council regrets to announce the death of the following Members of the Institution:—

Bywater, Frederick Jonathan, C.B.E. (Ringwood) M.1908; died 24th January, 1961.

Clapham, Thomas Alborn (Keighley) M.1930; died 27th January, 1961.

Gandon, Cecil Charles Vernon (Marseilles) M.1930; died 14th January, 1961.

McDonald, Alexander, B.Sc. (Leeds) M.1930 died 23rd January, 1961.

Personal Notes

Appointments

(*a*) *By Area Gas Boards:*

SCOTTISH GAS BOARD

Board Headquarters—

Senior Assistant Distributing Engineer: **G. B. Scott**

EAST MIDLANDS GAS BOARD

Burton on Trent District—

Distribution Engineer: **K. J. Hudson**

SOUTHERN GAS BOARD

Portsmouth Works—

Mechanical Engineer: **S. C. Noke**

(*b*) *Other Appointments:*

Mr. D. F. Blane (M) has recently taken up the appointment of Supervisor of Sales with the Inland Natural Gas Company, Limited British Columbia, Canada.

Mr. D. Harrison, B.Sc. (AM) has taken up the position of Research Officer, Burner Products, with Geo. Bray, Limited, Leeds.

Addresses Required

The Council would be grateful to receive the present addresses of the following members, last heard of in the places given in brackets:—

Mr. J. M. Attwood (Sheffield).
Mr. W. G. Bignell (Eastbourne).
Mr. E. Clark (Bridlington).
Mr. O. Clyne (Huddersfield).
Mr. S. W. Hayes (Braunton).
Mr. R. Spivey (Knaresborough).
Mr. E. F. Surti (Birmingham).
Lt.-Col. T. C. Whimster (Ashford).

District Sections and Affiliated Associations

(*a*) Notes of Meetings

DISTRICT SECTIONS

London and Southern Section

A large gathering of members and visitors attended the general meeting on Tuesday, 17th January, 1961, at the Caxton Hall, to hear a paper, entitled "Gas Characteristics as they Affect Utilization" given by Mr. L. W. Andrew (Director, Watson House Centre). Some excellent slides were shown illustrating the effect of several factors influencing the combustion of gas.

The vote of thanks was proposed by Dr. J. Burns, G.M. (Deputy Chairman, North Thames Gas Board).

JUNIOR GAS ASSOCIATIONS

Manchester District Junior Gas Association

A meeting of the Association was held on 18th January, 1961, when members paid an interesting visit to the Ashton-under-Lyne works of the National Gas and Oil Engine Company, Limited.

After a short address explaining the scope of the works, a detailed tour of about two hours was made through the various shops.

Following an interval for tea, a paper, entitled "Expanding Horizons", was presented by Dr. W. T. K. Braunholtz, O.B.E. (Secretary of The Institution of Gas Engineers), which gave rise to a good discussion.

The meeting concluded with a vote of thanks to the author, proposed by Mr. H. Dobson, who referred to Dr. Braunholtz's impending retirement and spoke appreciatively of his work for the Institution.

A vote of thanks was also given to the Directors of the National Gas and Oil Engine Company, Limited, for their hospitality.

Midland Junior Gas Association

A meeting of the Association was held in the Staff Mess Room, Birmingham, on Tuesday, 10th January, 1961, and was attended by 75 members. The President (Mr. R. W. Nelson) was in the Chair and welcomed Mr. P. R. Preston and Mr. J. P. Burnside of the South Australian Gas Company, Adelaide.

The President announced that Mr. A. W. Attwood had consented to become an Honorary Member of the Association. Mr. Attwood had given stalwart service to the Association, firstly in his capacity as Honorary Treasurer, and secondly as President during the early part of the Second World War.

The President then introduced Mr. R. L. Tarratt, B.Sc., (Divisional Mechanical Engineer, Birmingham Division, West Midlands Gas Board), who presented his paper "The Quest for Simpler Mechanical Maintenance on Gas Works". Mr. Tarratt emphasized some of his points with lantern slides.

Following a lively discussion, a vote of thanks was proposed by the Senior Vice-President (Mr. A. V. Wainwright).

Western Junior Gas Association

A meeting of the Association, attended by over 70 members, was held at the Bath Works of Stothert and Pitt, Limited, on Wednesday, 18th January, 1961.

Following a short introductory talk by Mr. G. Foster (General Works Manager), on the activities of the Company, members were conducted in groups through a representative number of departments. These included the large structural shop engaged on cutting and fabricating steel plate for large dockside cranes and other heavy plant, which form one of the Company's main products. This shop contains also a department engaged in hot and cold rolling of sections used for the production of large gear wheels.

The associated setting-out loft, where wooden patterns are made of all-plate work, was also seen. Of particular interest was the gas-fired equipment in this shop, including the largest plate-heating furnace in the South West, and stress-relieving and pre-heating furnaces.

The precision gear cutting shop aroused considerable interest, and members were able to watch the production of a wide range of gears to be used in the firm's products. Members also visited the modern general machine shops producing a variety of machined parts.

The ferrous and non-ferrous foundries contained several items of gas-fired plant, such as recirculating mould drying stoves, Acme core stove, a batch core oven, sand drier and ladle driers. Metal melting in the non-ferrous foundry is carried out in two Morgan tilting furnaces.

The toolroom, which produces a very wide range of jigs and tools for use throughout the works, was also visited.

In the heat-treatment department, a number of gas-fired carburizing and tempering furnaces were inspected together with a gas-heated metal-type fitting jig.

A portion of the contractors' plant department turning out transit concrete mixers and large vibrating rollers was also seen.

In the pump shop, a wide range of pumps for land and marine use was being manufactured. Various types and sizes of pumps are produced, individual designs being manufactured for such diverse liquids as primary flash distillate on the one hand, to molasses and heavy crude oil on the other.

In the heavy machine shop, the huge milling machines were engaged in machining large crane platforms to be incorporated in the newest type of tubular- and plate-fabricated, hydraulically operated dockside cranes now being produced.

At the conclusion of the visit, members were the guests of the Company for tea, following which Mr. J. Bowler proposed a vote of thanks to the Company, which was replied to briefly by Maj.-Gen. G. L. Watkinson (Chairman of the Company).

(b) Abstracts and Discussions of Papers

Copies of the complete papers abstracted below are available for consultation or loan in the Library of the Institution.

DISTRICT SECTIONS

London and Southern Section

"Oil Refinery Operations and Refinery Gas Production", *by G. R. Storey, B.Sc., Technological Department, Shell Refining Company, Limited.*

The paper was delivered in London on 22nd November, 1960, and the discussion is on p. 70 of the Journal, Vol. 1.

The primary feedstock of a modern oil refinery is "crude" oil obtained direct from the oilfields. This crude oil is processed on the refinery in three broad groups of process unit. These are, the physical separation processes, the conversion processes, and finally the treating processes. In the first group of plants, the crude oil is split into fractions using mainly fractional-distillation equipment. These fractions may be finished products in themselves, or may require further processing.

Conversion processes are used to alter the product yielded from crude oil to suit the pattern of products demanded by the market. There are many of these processes, perhaps the most important being catalytic cracking and thermal and catalytic reforming. In catalytic cracking, heavy products from the distillation plants are converted into gas, gasoline and other products. Thermal and catalytic reformers are used to improve the quality of kerosine fractions and make them suitable for inclusion in high quality

gasolines. The throughputs and operating conditions of the conversion plants are adjusted to prevent over-production of any one group of products, with the consequent storage problem, and to adjust the quality of the final products.

Many of the products from the plants already mentioned are not yet suitable for sale and some form of treating to remove contaminants is still required. The main contaminant is sulphur, and many processes are used for its treatment. The product stream can either be "sweetened", as in the well-known Doctor process, where mercaptan molecules are converted to disulphides with consequent odour improvement, or the entire sulphur-containing molecule can be removed in extraction processes. For the higher molecular weight products, catalytic desulphurization processes are increasingly used in which the sulphur is removed as hydrogen sulphide.

The gases produced on an oil refinery (butane and lighter) can be used in various ways. Where thermal reforming and catalytic cracking processes are utilized, the gases have a high olefin content and are thus valuable feedstocks for chemical plants (solvent manufacture, alkylation, plastics, *etc.*). Propane and butane may be sold as liquefied petroleum gases in the familiar cylinders. The lighter gases are used as refinery fuel or are available for sale to outside buyers, such as the gas industry.

Because of the ever-changing pattern of refinery operations, the varying types of crude oil, the need for periodic plant shut-downs, *etc.*, a guaranteed supply figure to an outside user on a daily basis is generally only a proportion of that normally available. When gas is sold to the Gas Boards, it is generally given a rigorous treatment to remove contaminants, generally hydrogen sulphide and water, to a very low level. The treatment processes are conventional in character, but are noted by the intensive use made of instruments for quality control. The use of these instruments safeguards the customer against fluctuations in quality by giving the operator of the process early warning of possible plant upsets, thus enabling him to take corrective action.

"Gas Characteristics as they Affect Utilization", *by L. W. Andrew, B.A., B.Sc., M.I.Gas E., Director, Watson House Centre, North Thames Gas Board.*

Paper delivered in London on 17th January, 1961.

The author deals with the common interests of the utilization of gas and the gas manufacturing side under the following headings :—

How Gas Characteristics Affect Appliance Performance

This deals with those combustion characteristics of gas that affect the safe and satisfactory performance of an appliance over a reasonable period of time. The main characteristics can be defined in terms of the Wobbe number and the burning velocity expressed empirically in terms of the aeration test burner, the non-aerated flame height burner, and the reversion pressure test burner.

Safety.—The characteristics affect safety from the point of view of the completeness of combustion and the stability of both aerated and non-aerated flames ; also the possibility of sooting.

Other characteristics, such as sulphur content, rust, or gum, also affect to a marked extent the maintenance characteristics of appliances.

User Performance.—User performance is a basic consideration, and of particular importance is the maintenance of the correct heat input.

Appliances are different in sensitivity, the instantaneous water heater being the most sensitive, and, generally speaking, the permissible limits of Wobbe number for a gas are ± 5 per cent, although a drop to 10 per cent may be permissible for short emergency periods.

The distribution of gases in terms of Wobbe number and aeration number are discussed. Attention is drawn to the fact that an appliance is approved on the assumption that it will function over a known range of gas characteristics.

Assessment of New Types of Gas

If new gases are supplied to the industry, then steps must be taken to ensure that either (i) the gas has satisfactory characteristics for the appliances already on the district, or (ii) existing appliances are modified to burn the new gas satisfactorily. It is now possible, from the analysis of a gas, to predict the combustion characteristics and to decide whether or not the gas is likely to be interchangeable with gas already supplied. The prediction diagrams on which this decision is based are discussed.

Interchangeable Gases

Butane/Air Additions.—The effect of butane/air is discussed, and the conditions under which 10 per cent or more of this can be added to G4 gas to give satisfactory results.

Carbon Monoxide Conversion.—Examples are given showing the effect of the water gas shift reaction and the conditions under which a high proportion of carbon dioxide can be left in the final gas with a satisfactory Wobbe number and combustion characteristics.

Attention is drawn to the conditions under which a high proportion of carbon dioxide might affect gas services.

Gases of Increased Calorific Value.—There is some discussion on the possibilities of increasing the calorific value of gases that would otherwise be of too low a Wobbe number.

Non-Interchangeable Gas

This means modifications to appliances, and such modifications are considered under four headings :—(1) The substitute gas is similar in burning velocity, but differs in Wobbe number by approximately one gas group ; (2) The substitute gas is similar in burning velocity, but differs in Wobbe number by more than one group ; (3) The substitute gas has a lower burning velocity and has about the same Wobbe number as the original gas ; (4) The substitute gas has a lower burning velocity and differs in Wobbe number. The methods of dealing with each of these gases are considered, including the use of a change-over gas as a temporary phase.

Conclusions

The author suggests that our knowledge of combustion characteristics makes it important to co-operate on an ever-increasing scale with the manufacturing engineer in order, on the one hand, to make the most of flexibility of gas production and, on the other, to ensure the provision of a really continuously satisfactory service to the user.

Discussion

Mr. J. E. Davis, O.B.E. (Croydon) said it was now possible to obtain freedom to control gas characteristics, but only to within certain limits. The gas industry could afford to spend a great deal of money to ensure satisfactory service, and he considered it a very uneconomic proposition at times of peak demand to lose possibly up to 10 per cent of the potential output by failure to provide the gas at the correct Wobbe number. He summed up recent knowledge of combustion characteristics as giving new liberty, but not new licence.

Mr. T. V. Garrud (London) thought the paper was perhaps the most important in the Section's programme, and he hoped it would be fully reported in the new *Journal* of The Institution of Gas Engineers as being a paper with a very wide application to all sides of the industry. He reminded the audience that gum difficulties had now disappeared, corrosion due to sulphur was on the way out accompanied by extended periods of maintenance of appliances, but, at the moment, nuisances due to rust were still prevalent.

Mr. E. O. Rose (Hatfield) considered the paper most opportune at a time when new methods of gas production were being implemented. The gas engineer had two alternatives: either the appliance should be made to suit the gas, or the gas should be made to suit the appliance. When integration of works was carried out, a district might be served with gas from different sources, and the

type of gas from these sources should be interchangeable. The small works that could not be economically integrated presented a special problem. The supply of liquefied petroleum gases mixed with air had the advantage of being sulphur-free, but the density was high and so far there seemed to be no standard for appliances supplied with such mixtures. In reference to the use of Prigg's diagram, he said he was always a little doubtful of satisfactory performance of a gas the characteristics of which approached the confines of the diagram.

Mr. W. F. Thorne (Southampton) said there were specifications for the industry's secondary product—coke—but no real specification for the primary product, gas. He said there was no consideration given in the paper to the net calorific value of gas, which normally is what the appliance gives. He mentioned that 25 per cent of the gas supplied by the Southern Gas Board was now derived from refinery gas and its low sulphur content at 3·5 gr/100 cu. ft had resulted in a large number of enquiries for flueless heaters.

Mr. L. T. Minchin (London) considered there was still room for improvement in the relations between appliance manufacturers and Gas Boards, and that gas engineers did not give much consideration to the Wobbe number of gas. He also suggested that the Gas Regulations should allow for a weighted mean calorific value over the year to allow high-calorific value gas to be distributed at peak output. Some authority should also calibrate all test apparatus.

Mr. L. J. Clark, B.E.M. (London) questioned the rigidity of the limits of the Prigg diagram and suggested that gas pressures could be increased to counteract high Wobbe numbers. He asked also what was the loss of efficiency for gases falling outside the limits.

Dr. J. R. Dewhurst (London) maintained that the characteristics of gas should be such that its position in Prigg's diagram should lie in the centre band, well away from the confines, and thus ensure that the consumer obtained good service.

Dr. J. Burns, G.M. (London ; Deputy Chairman, North Thames Gas Board), said that Watson House was carrying out some excellent work and that the paper was a very clear exposition of a difficult subject ; moreover, an understanding of the combustion characteristics of gas was of vital importance. He referred to the many standards and limits the industry was imposing on itself without any outside compulsion, and drew attention to the anomaly of the very low limit for hydrogen sulphide of about 1 p.p.m., whereas there was no limit for organic sulphur compounds, which, in a concentration of 1 gr/100 cu. ft was equivalent to 17 p.p.m.

Author's Reply

Mr. L. W. Andrew replied individually to the many points raised by members in the discussion, which, the **Chairman** said, was very well informed and a tribute to the usefulness of the paper.

North of England Section

"Engineering Comparisons of Two Recently Constructed Gas Works", *by W. R. Garrett, M.I.C.E., M.I.Gas E., M.I.Struct.E., Constructional and Consultant Engineer, Northern Gas Board.*

Paper delivered in Newcastle-upon-Tyne, on 1st December, 1960.

The author compares the differences in design and layout of two intermittent vertical carbonizing plants of identical capacities, one of which was completed in 1951 at Howdon-on-Tyne, and the other at Sunderland in 1960, which was officially opened by the Minister of Power, on 28th October, 1960.

The author states that the defects and errors of judgment in the older installation have been removed and where possible the new installation has been improved and built to reduce cost of repair and maintenance. Capital costs have been reduced by omission of all but the absolute necessary spares.

The shape of the ground space available for development in the recently completed plant has made it possible to produce a better engineering lay-out, on a slightly smaller site, than the plant constructed nine years previously.

Improvements between the years 1949 and 1957 have been embodied in the new plant, but these are of relatively minor importance.

The paper concludes by expressing doubts on the wisdom of placing such entire projects in the hands of one contractor.

JUNIOR GAS ASSOCIATIONS

London and Southern Junior Gas Association

"Choosing a Flame Protection System", *by N. D. B. Harris, M.I.Gas E., (Perl Controls, Limited).*

Delivered in London on 6th January, 1961.

The increasing number and variety of flame-failure controls makes choice of a suitable system a difficult matter for a gas engineer who is not a specialist in this field. The object of the paper is to provide a simple guide to assist in selection of appropriate devices for any given use. No manufacturer's products are mentioned by name or described in detail, but instead the fundamental principles of operation of all available devices are used as a basis of classification.

Devices with an almost instantaneous response have an electronic basis and depend for their action on (1) photo-electric effects, (2) flame conductivity, and (3) flame rectification. Devices of this type are described in the paper, and difficulties that may be encountered on installation are listed.

Systems giving an instantaneous response are usually more expensive to apply than those in which the response is delayed, but in many instances such a delay can be tolerated. Devices with delayed response also fall into three basic types : (1) bimetallic, (2) unimetallic, and (3) thermo-electric. Each type is described in the paper.

The final selection of a flame-failure protection system follows from the answers to three questions : (1) How is the flame to be ignited? (2) How is the burner controlled? (3) Is a delayed response permissible?

On this basis, coupled with a consideration of operating conditions, a suitable system can be chosen using the two figures in this paper, which cover all currently available devices.

Discussion

The discussion on the paper ranged over the whole field of flame protection, and the Industrial Gas Development Committee's report on "Flame Protection Practice, 1956" was recommended as a useful adjunct of which insufficient use had been made in the past. Manufacturers' literature also often contained useful technical information, though necessarily limited in scope to the products of the firm concerned.

Makers' catalogues might also be expected to furnish details of price, which was another point raised in discussion. To judge from the range of prices quoted in the discussion, it appears that costs might well prove to be a determining factor in the choice of a suitable flame protection system where technical considerations made it possible to use more than one type of equipment. The statement, in the paper, that instantaneous-response controls were more costly than the delayed-response types was also borne out by prices quoted.

Some members were intrigued by the use of the flicker of a town gas flame as a means of discriminating between the radiation from a flame and a hot background such as furnace brickwork. Oil flames tended to be more luminous than town gas flames, so that systems based on detection of the presence of light from a flame could be applied to oil furnaces. Nevertheless, gas was now sold for heating purposes, and flame luminosity was simply an incidental feature that might or might not be present, according to methods of manufacture and other materials used. Under these circumstances, the detection of flame flicker as an actuating signal was clearly far more reliable than the detection of presence of radiation from a town gas flame.

The types of pilots to be used in association with flame-protection equipment were also discussed. It is possible to have trouble with the detection of such pilots by the devices concerned because of the tendency of certain burners to emphasize the dead space between the burner orifice and the root of the flame. The use of Bray jets or aerated burners was recommended, while pinhole jets appeared to give trouble in some cases.

The need for regular maintenance, mentioned by the author, was emphasized in discussion, and this led to the subject of reliability. The incorporation of " safe-start " features in flame-protection equipment was noted as a desirable factor. It was pointed out that if, during shut down, flame-failure conditions were simulated, the equipment could be proved regularly. Electronic components could now be regarded as robust enough and reliable enough for use in industrial equipment, and in any case failure would lead to a safe condition in all equipment at present marketed. Nevertheless, there are degrees of reliability of flame protection systems ; for instance, those involving programming units might or might not incorporate a feature safeguarding against the failure of the programming motor.

While most of the developments in the past had been for industrial and commercial applications, the future held great possibilities in the domestic field. Even now, automation in the home was a fact ; whole-house heating demanded flame protection, but many other domestic applications could be foreseen. With a market for millions of controls, costs could be reduced to an acceptable level. Possible sources of suitably cheap equipment lay in delayed-response devices, and two categories not mentioned by the author were described in discussion, namely, (i) thermopneumatic devices, and (ii) thermomagnetic systems.

In thermopneumatic devices, the flame was detected by the expansion of a fluid contained in the device. In some tests that had been conducted, using air as the fluid, escape of the air had led to failure of the device, though such a failure would leave an appliance in a safe condition. Further development work might well overcome such difficulties.

Thermomagnetic devices depended for their action on the temporary destruction of " permanent " magnetism in a flame detection device designed to allow a gas valve to open on the disappearance of the magnetism when the device was heated.

The general impression left by the discussion was one of fulfilment of industrial and commercial needs by a variety of equipment and of the immense opportunities offered by the domestic field in a society whose standards of living were increasing.

"Planning Small Holder Stations to Reduce Operation and Maintenance Costs to a Minimum",

by R. G. Langford, A.M.I.Gas E., Assistant Distributing Engineer, East Surrey Division, South Eastern Gas Board.

This paper, which won the London and Southern Junior Gas Association President's Prize for 1960-61, was delivered in London on 6th January, 1961.

The introduction to the paper stresses the need to maintain the overall operating costs of a distribution system at a minimum to sustain the economic advantages of concentrated production.

It describes the general principles applied to the replanning of a group of small gasholder stations with the principal aim of replacing old plant and reducing operating costs. It demonstrates that the cost of new installations can be economically justified and can provide automatic plant and equipment that will allow the station to operate satisfactorily unattended.

The site plan of a redeveloped holder station demonstrates that the new plant can be concentrated in a fenced area of limited size, which can include, for example, a vehicle parking area and a local distribution equipment store.

The layout of a typical installation is discussed and is supported by comprehensive descriptions of the jet-boosting and mechanical-boosting plant, the automatic holder valves and station governors, and their respective control systems.

Further paragraphs describe the electric heating installation for the prevention of ice formation in holder water, and the instrumentation equipment used in conjunction with the public telephone system for monitoring the principal functions controlled by the plant.

The importance of overall and day-to-day supervision of the stations is stressed, and emphasis is placed upon the choice of the right type of personnel for these duties.

Discussion

Mr. C. H. Townsend (Orpington) referred to the chain-link fencing around the holder stations, and asked whether this had been found to be " small-boy proof ". He supported the proposal for the installation of an internal heater for the electric motor, as he had recently experienced at Wandsworth a build-up of condensation inside the casing of a motor that had been shut down. He felt that some form of heating ought to be installed for the control equipment and instrument panel.

Mr. Townsend enquired whether the electrical anti-freeze was the " all-on " or " all-off " variety. Referring to the " Dataphonic " equipment, he wished to know what happened when the equipment was due to communicate with the control-room under emergency conditions and the control-room telephone was engaged.

Mr. F. T. Buist (London) also referred to chain-link fencing. He had found it completely " small-boy proof ". He added that the author was installing variable-control governors in the control-kiosk, and mentioned the case where a variable-control governor could be installed in a pit and adjusted remotely by the use of a Bowden cable control.

Mr. C. D. Shann (London) said that in the photographs shown all mains and governors were above ground, but that the author had mentioned the construction of governor pits.

Mr. C. P. Browne (Croydon) remarked that obviously he had no criticism to make concerning the paper, since he was more than somewhat involved in the work referred to therein, but he answered two queries that had already been raised in the discussion. The chain-link fencing they had found quite " small-boy proof ", particularly with the addition of three strands of barbed wire along the top posts. In reply to Mr. Shann, Mr. Browne said that originally the holder stations had been planned for all mains to be above ground. Nevertheless, in spite of the original proposals, it had now been decided, as a matter of policy, that all the mains should be covered and the governors installed in the pits.

Mr. R. L. Norton (London), referring to the increasing number of such stations, considered it highly desirable that all volumetric governors on the inlets to unmanned holder stations should be remotely controlled so that the overall requirements, on a day-to-day basis, of small holder stations should be reasonably equivalent to the average production make on the works supplying the holder stations.

Mr. D. H. F. Birchell (Portslade) enquired whether the electric motors referred to were flame-proof, and also the purpose of the dividing screen between the motor and the booster.

Questions were also raised as to the dangers of freezing of the auxiliary-system governors, and what steps were being taken to overcome this eventuality. One member felt that a further paper, giving more detailed information concerning electrical anti-freezing of gasholders, and of the "Dataphonic" equipment, would be fully justified, since in the limits of the short paper presented by Mr. Langford reference to these two items was extremely limited. In referring to the author's point that all trees and grass should be removed from the holder site, one member considered that this was a great pity, since trees, under certain circumstances, acted as camouflage for holders and other plant.

Author's Reply

Mr. R. G. Langford, replying to the above, said that the "Dataphonic" equipment would automatically continue to call the control-room on seven occasions should the number be engaged when the call is first made.

Referring to the question by Mr. Townsend on holder heating, the author replied that each circuit was individually controlled by a thermostat and it could be possible for the heating in the top cup of the holder to be automatically switched on before that of the bottom cup.

Mr. Langford added that the question of chain-link fencing had already been dealt with by Mr. Browne in his contribution, together with the question of the mains above ground.

Mr. Langford agreed with Mr. Buist that the pilot control governors could be installed in the pit and remotely controlled *via* Bowden cables, but in the installations discussed it was decided to install all variable-control pilot governors in the control-kiosk, together with recorders and other instruments, which, in reply to another question, was stated to have installed within it a flame-proof tubular heater. This, of course, would overcome the difficulty of the variable-control governors freezing. It was considered by the author that permanently loaded pilot governors are not so inclined to freeze ; therefore, these were installed in the pit of the main governor.

Replying to Mr. Norton, Mr. Langford agreed that the volumetric input to holder stations is a matter of some importance to the production engineer, but that the holder stations referred to in the paper were virtually satellite stations of a parent holder station that actually supplied the gas. This parent holder station, receiving its supply from a works, was manned ; therefore, the volumetric input from the production works was readily adjustable.

In reply to Mr. Birchell, Mr. Langford stated that the electric motors were weather-proof and not flame-proof, and in view of this a dividing wall had been erected between the motor and the booster, to overcome any chance of a flash explosion that could otherwise result.

Dealing with the remark regarding the removal of trees and grass from the sites, the author stated that this decision had been taken purely in the interest of absolute maintenance economy.

"Fluid Coupling", *by P. A. W. Styles, Assistant Engineer, Southampton Works, Southern Gas Board.*

Paper delivered in London on 6th January, 1961.

The use of a.c. motors to drive a great variety of machinery in gas works has been increasing rapidly in recent years.

The squirrel-cage motor is simple and efficient at working speed, but, in a number of applications, suffers from its poor starting torque and constant-speed characteristics. The use of fluid couplings can overcome these difficulties and can be of value in other applications with both electric and diesel drives.

After a brief history of the development of fluid couplings, the paper describes the general principles of a centrifugal pump driving a turbine impeller in a closed fluid circuit. This is followed by descriptions of the various types of fluid coupling, *viz.*

(1) the traction-type couplings with their advantages of being able to accelerate the drive smoothly after the motor has gained speed, and also to limit the torque transmitted and damp out torsional vibrations.

(2) The scoop-type couplings with their additional advantages of speed control.

The paper concludes with a brief description of some applications of fluid couplings in the Gas Industry.

Discussion

Mr. C. H. Townsend (Orpington) agreed with the author's claims for the advantage of fluid couplings. He spoke of successful application at East Greenwich to coal crushers and diesel locomotives. In each case, the duties were severe. He was puzzled about the lack of applications for scoop-control couplings in spite of advantages for speed control.

Mr. F. T. Buist (London) spoke of his experience with fluid drive for boosters, and agreed with the author's claims for ease of starting and smooth running.

Mr. S. H. Woodham spoke of the simplification of starting gear when fluid couplings were used.

Mr. H. T. Lockwood (Southampton) gave details of the boosting and exhausting plant at Southampton, using both electric and diesel drives. The maintenance of plant was very low. It had been possible to reduce motor sizes and simplify the starting gear.

Mr. P. J. Savage (President ; Woodford Green) gave details of the application of fluid couplings to carburetted water gas plant grate drive, also of an exhauster controlled by fitting the governor to the scoop controls of the fluid drive.

Author's Reply

The Author, in reply, spoke of each contributor's agreement with the advantage of fluid drive. He said that electric starting gear could be simplified and that boosters and exhausters could be as easily controlled as with steam drive.

Manchester Junior Gas Association

"Expanding Horizons", *by W. T. K. Braunholtz, O.B.E., M.A., Ph.D., F.R.I.C., Secretary, The Institution of Gas Engineers.*

Paper delivered in Ashton-under-Lyne on 18th January, 1961.

The author draws attention to the tremendous expansion in gas consumption in countries fortunate enough to have a plentiful supply of cheap gas, e.g. natural gas. Tabulated statistics are given for the United States of America, Canada, France, and the U.S.S.R., with particular reference to the annual consumption of natural gas, manufactured gas and other types of gas, and the consumption per domestic and industrial consumer.

In the United States of America, the total gas consumption and the consumption per domestic consumer have roughly doubled in the last 10 years. In Canada, the total consumption has quadrupled in the last 10 years, and the consumption per domestic consumer has doubled in that period. In France, following the discovery of natural gas at Lacq, the total consumption has roughly quadrupled in the last 10 years, and the natural gas resources have more recently been greatly extended by the discoveries in the Sahara. In Soviet Russia, vast reserves of natural gas have become available within the last few years. Between 1959 and 1960, gas production increased by 32 per cent, and in 1965 it is expected to be four times that in 1959. This will bring the production in Russia, on a thermal basis, to about 20 times the current

annual production in Great Britain, and more than one-half the current production of the United States of America.

The potential increases in gas consumption will depend upon a variety of factors in each country, but the figures quoted give an indication of what has been achieved under favourable conditions.

The second part of the paper outlines the origin, membership and activities of the International Gas Union, which was formed on the joint initiative of The Institution of Gas Engineers and the French Gas Association at the time of the 68th Annual General Meeting of the Institution in 1931. The Union, in addition to organizing an International Gas Conference every three years, has an active Council and standing committees. It promotes co-operation and cordial relations between the national associations of gas engineers and their members and is a useful channel for exchanging information about new developments in the various countries.

Discussion

Mr. J. A. Taylor (President), thanking the author, said it was interesting that during their tour of the works they were told that engines were being supplied to the Argentine for use on natural gas.

Mr. H. Partington (North Cheshire) said the expansion of the gas industry appeared to depend on the price of gas. He asked if the author could give further information about work in this country in the search for natural gas and about the prospects of success.

Mr. G. Brook (Liverpool) referred to the great increase in gas sales in France in spite of the fact that natural gas represented only 7 per cent of the gas supplied. He asked if this percentage would be sufficient to enable the gas industry in this country to go ahead quickly.

Mr. J. R. Teale (Central Lancashire) agreed that the distribution and industrial engineers would welcome cheap gas, but he wondered what had been the effect in other countries on the gas-producing stations.

Mr. N. Wickstead (Wigan) was impressed by the consumption per domestic consumer in the United States. He asked if gas is outstripping electricity and solid fuel in this field.

Mr.--Curry (Blackpool) thought the vast storage capacity for gas in the United States, Canada and France helped to make the gas cheap. If natural gas is not found in Britain, and has to be imported from overseas, would it not intensify our storage problem?

Mr. J. K. Lord (Manchester) said the figures for gas consumption are almost entirely dependent upon the price of gas in comparison with competitive fuels. He would like to know the price of gas in other countries.

Mr. D. W. Hamlyn (Manchester) asked what is the expenditure in other countries on research and development in relation to the total turnover.

Author's Reply

The **Author**, in replying, said he could give no information beyond what had been published about the results and prospects in the search for natural gas in this country. They knew that natural gas was being used in Scotland and in Yorkshire, but boring had not yet gone as deep as at Lacq, for example, where natural gas was found at a depth of about 12,000 ft. It was hot and high in sulphur and had presented serious difficulties from corrosion of the collecting pipes. However, these had been successfully overcome, the sulphur was now being recovered and, indeed, France had become one of the principal sulphur-producing countries in the World.

The expansion of gas consumption depended on a number of factors, which varied from one country to another. Perhaps, of the countries quoted, conditions in France are clo.est to those in Great Britain. There the available natural gas is still supplementary to manufactured gas. With regard to storage, there have been great developments in the storage of gas underground, and this might well be the answer if natural gas were found or imported in quantity in this country.

The **Author** regretted he could not answer the various questions on the economic side. He had had to limit the scope of his paper to an indication of certain aspects only, but he thought a more detailed study of all the operative factors would be both interesting and rewarding.

Midland Junior Gas Association

"The Quest for Simpler Mechanical Maintenance on Gas Works", *by R. L. Tarratt, B.Sc., M.I.Mech.E., A.M.I.Gas E., Divisional Mechanical Engineer, Birmingham Division, West Midlands Gas Board.*

Paper delivered in Birmingham on 10th January, 1961.

The paper opens with a brief description of power and steam utilization up to 1935, and compares the low efficiency associated with steam-driven auxiliaries and atmospheric exhausts with modern means of using all the steam generated in high-pressure waste-heat boilers only. All high-pressure steam is concentrated either on a back-pressure or a pass-out turbo-alternator set according to the low-pressure steam requirements.

The much greater efficiency of the modern steam system, which utilizes the latent heat in the steam for process work, fully justifies the complete changeover from steam to all-electric drives.

The conversion of some existing steam reciprocating pumps to electric drive is described, and an estimate is made of the full requirements for pumping liquids by centrifugal pumps. Four examples of centrifugal pumps applied to special duties are given to show that this type of pump can meet all gas works needs if care is taken to avoid a suction lift.

The development of mechanical seals is mentioned as an alternative to packed glands for high-speed pumps, as a way of reducing mechanical maintenance.

The limitations of standardizing electric drives with squirrel-cage motors and direct-on-line starters is explained, and examples of devices for overcoming poor starting torque and variable-speed difficulties are given.

A reliable and inexpensive method of providing variable outputs of air for purifiers is offered as an alternative to using variable-speed d.c. motor drives.

Mechanical maintenance has been greatly reduced by replacing reciprocating mechanical feeder gears with electric high-frequency vibrating-tray feeders.

Experiments with different materials for belt-conveyor idlers, to overcome corrosion difficulties, are described ; the results led to a specification for standard idlers, requiring no external lubrication.

Some experimental work on materials for conveyor gravity and lip buckets and cams led to a reduction in the weight of conveyor chains, and the possible effects on power requirements and chain wear are discussed.

Some examples of mechanical safety devices applied to different driving gears are given and the need for adequate overload capacity in such gears is explained.

Some notes are included on lubrication, and mention is made of special lubricants, and also some new materials that are nearly self-lubricating.

The paper concludes with suggestions for reducing mechanical maintenance by making better use of the experience gained from the operation of existing plant. Some mistakes would not be repeated if more detailed specifications were issued to contractors to assist them in preparing designs to suit local requirements. The issue of more detailed preliminary drawings by contractors for approval before erection begins is also stressed as an aid for improving plant operation and maintenance.

Discussion

Mr. S. Brockbank (Newcastle-under-Lyme) said that good mechanical maintenance was vital to the gas industry and that Mr. Tarratt was right to stress that attention to plant design was very important. On the subject of gravity-bucket conveyors, he recalled an instance, some time ago, where, due to the type of sprocket drive, there was some doubt as to whether the conveyor would prove to be satisfactory. The contractors concluded that the velocity of the drive would have to be varied as the chain turned over the sprocket. They therefore provided egg-shaped gears, which, in turn, caused a variation in the speed of the drive, the result of which was disastrous if the timing was incorrect.

As to the question of the saving in horse power as a result of using lighter buckets, more power would obviously be required to raise a heavier bucket, but this would be offset when it passed the driving sprocket and descended on the other side. The point at issue was, therefore, not the power required, but the amount of friction encountered.

Referring to the reduction in chain tension by using asbestos cement buckets and aluminium cams, he thought the figure quoted in the Paper was rather low. He asked also if Mr. Tarratt had any experience of fabric gears.

The **Author** replied that he had not seen any egg-shaped gears used on gravity-bucket conveyors, but thought there were examples on view at the Science Museum, South Kensington. He agreed that some acceleration of the chain was inevitable : this could be proved by fitting an ammeter, which would be seen to " flick " every time a link passed the sprocket. The acceleration should not, however, be great, since the speed of the chain would usually be limited to 50 ft/min. As to the question of horse power and chain tension with light-weight buckets and cams, chain tension was lower, due to the reduced weight, whereas the horse power required was affected by friction of the chain travelling along the top and bottom horizontal tracks. He added that the figures he had quo.ed took into account increased tension plus friction and, although calculated, were fairly accurate.

Mr. Tarratt said that fabric gears were little used and it was usual to fit double helical gears on high-speed shafts.

Mr. C. Halstead (Birmingham) enquired if the fibre-glass buckets referred to in the paper could be repaired, and, if so, was it economical to do so.

The **Author** replied that they could be repaired if holed, but the manufacturers were not prepared to attempt repairs to buckets that had cracked or were mis-shapen.

Mr. F. J. Bengough (Birmingham) considered the paper a good one, but pointed out that, although as a Works Engineer himself, he was looking for easier maintenance, he was more concerned with cheaper maintenance. Where plant was operating on a high load factor, there was a lack of maintenance that was aggravated by the shortage of skilled maintenance personnel.

He agreed that the gas industry had been somewhat lax in the past in not giving sufficient attention to design. It by no means followed, he said, that plant ordered some years ago should be replaced with exactly the same type of plant ; it was surely logical to look into the possibility of an improvement in design. If, therefore, Mr. Tarratt had in his paper made this point clear to all, then he had done a good job.

Mr. Bengough said he was not quite clear what Mr. Tarratt meant by saying that " . . . when a worm reduction unit is to be included in the driving gear for an inclined belt conveyor or a lip-bucket conveyor, it should be remembered that all high-efficiency gears of this type are reversible ".

The **Author** replied that in his experience there were engineers who still thought that worm gears would not run backwards, and proceeded to explain the circumstances in which this could and did happen; anti-run-back gear was, therefore, essential.

Mr. A. Griffiths (Wolverhampton) said that Mr. Tarratt had made a reference to tests with trial gravity-bucket and lip-bucket conveyors, but there was no further reference to the latter, and he enquired if Mr. Tarratt had any experience of asbestos lip-bucket conveyors. In the case of asbestos buckets and aluminium cams, had Mr. Tarratt any experience of the wear on the dumping cams? Mr. Griffiths said that before joining the Gas Board, his experience was that drawings were always sent to the purchasers and their approval obtained before any work was commenced, but this did not seem to be the practice today. He was, therefore, very pleased to see that Mr. Tarratt had made this point.

The **Author** replied that lip-bucket conveyors had not been mentioned in connexion with asbestos buckets because this type of bucket had been restricted to gravity-bucket conveyors. Both welded- and cast-aluminium buckets had been applied successfully to lip-bucket conveyors without undue wear of the lips. With asbestos buckets, the cams were backed with aluminium plate to strengthen the cam attachment. The dumping cams had not been altered.

Mr. Tarratt said that although, at the present time, often no drawings at all were received from contractors, this had not always been the case. This meant, of course, that, in the event of a break-down, engineers were sometimes confronted with the problem of how to tackle the necessary repairs.

Mr. R. N. Ha:eley (Birmingham) said that one often found that one side of a gravity-bucket chain was under very heavy tension while the other side was slack. He asked if Mr. Tarratt approved of the practice of turning the chain over and splitting it up into pieces before refitting. Mr. Ha.eley agreed that if an asbestos bucket became wedged it was likely that many buckets would be damaged, and he asked if a safety device could be fitted.

The **Author** said it was difficult to say why a chain stretched more on one side than the other. It could be due to the fact that one side was in closer proximity to a source of heat (e.g., a producer) while the other was more easily washed with a hosepipe. The conveyor might not have been correctly aligned, but there could be no definite answer without knowing the local conditions.

The practice of turning over short lengths of chain to distribute wear equally on each side would possibly add a year to the life of a chain.

As to damage to asbestos buckets if one of them became wedged, Mr. Tarratt said he was hoping that the electrical engineer would be able to design some kind of cut-out to prevent this happening.

Mr. L. H. Hardy (Birmingham) referred to the tests on welded-aluminium and cast-aluminium buckets, and enquired if Mr. Tarratt thought that these buckets had been under test long enough for one to be able to say which type was to be preferred.

The **Author** said that on some of the Birmingham gas works the welded type were giving better service, but on others the preference was for the cast type. It could, however, be said that the welded type generally ran cleaner than the cast type, which tended to become coated with fine dust deposits, *etc.* He felt, therefore, it was too early to say which was the better bucket.

Mr. K. J. Crane (Birmingham) pointed out that, in his paper, Mr. Tarratt had made no mention of blanket conveyors.

The **Author** replied that, with the exception of Mill Hill, where they operated at an angle of 35° as compared with the usual maximum of 17° for a normal belt conveyor, they were little used in this country. Nevertheless, with more experience of this type of conveyor there would, no doubt, be instances where they could be installed with advantage.

Mr. N. G. Earle (Redditch) confirmed Mr. Tarratt's view on the merits of welded- and cast-aluminium buckets, but said that on his works the cast type that had been installed cost about 70 per cent that of the welded type. Mr. Earle said that, in referring to scoop-controlled fluid couplings, Mr. Tarratt had said in his Paper that the output speed could usually be varied by 3:1 ratio ; in his experience, however, manufacturers often claimed that this variation could be as much as 7:1.

Mr. Earle said also that at Redditch rollers made of aluminium instead of cast iron had been used successfully on gravity-bucket conveyors for about 12 months.

Regarding the lubrication of conveyor chains with colloidal graphite, he enquired if this meant that dirt, *etc.*, was washed into the bushes.

The **Author** said that cast-aluminium buckets were slightly cheaper than the welded type, but not by as much as 30 per cent. Mr. Tarratt explained how he arrived at his conclusion that the output speed of scoop-controlled fluid couplings could be varied by 3:1; in his view, manufacturers did not claim a variation of 7:1.

Aluminium rollers had been in use on a conveyor chain at Solihull Works, Birmingham, but they had shown excessive wear after 18 months and were not, therefore, considered suitable.

As to the use of colloidal graphite for the lubrication of conveyor chains, Mr. Tarratt said he was at first very doubtful whether this method would be successful, but the graphite was applied to the chain with a light spirit, sufficient only to carry it, and there was, therefore, little risk of it washing dirt into the bushes.

Mr. J. Hatfield (Derby) referred to the stretching of conveyor chains and said this was often confused with the extension in the length of chain due to the enlargement of the holes in the links. He said that on his works these chains were lubricated by using a high-pressure grease gun of a type similar to those used in garages.

Referring to the building up of worn pump shafts, *etc.*, by means of deposits of chrome or nickel, Mr. Hatfield enquired if Mr. Tarratt had any experience of the use of ceramics for this purpose.

Regarding the thermal efficiency where high-pressure steam was passed through a back-pressure turbo-alternator and fully utilized for process work, he questioned whether it was fair to compare this efficiency, stated to be 65 per cent, with the average generating efficiency of the Central Electricity Generating Board's turbines, given as just over 26 per cent.

The **Author** agreed that the term " stretching " in connexion with conveyor chains was wrongly used : the apparent extension was caused by excessive wear at the link holes. Mr. Tarratt agreed also that the use of a high-pressure grease gun for lubricating conveyor chains was a good idea, provided maintenance personnel could be relied upon to do the job conscientiously. He added that he had no experience of ceramics for building up worn shafts. In large pumps, the shaft sleeves were usually of bronze, but small pumps did not usually have sleeves to protect the shafts, and for this reason the building up process by specialist firms had proved very successful. This meant also a reduction in wear on gland packings. The 26 per cent generating efficiency of the Central Electricity Generating Board's turbines was not as high as one might suppose and he was surprised that they did not make more use of the back-pressure turbo-alternator. The problem was to use the latent heat of the steam, and if that could be done then it should be possible to attain an efficiency of 70 per cent on the larger steam turbines.

Mr. A. V. Wainwright (Senior Vice-President) complimented Mr. Tarratt on his paper and on the slides he had used to emphasize his points.

Scottish (Eastern) Junior Gas Association

"Industrial Gas in the Central Division", *by D. Murray, A.M.I.Gas E., Divisional Industrial Sales Officer, The Scottish Gas Board.*

Paper delivered in Dundee on 7th January, 1961.

As an introduction, the author outlines the various steps being taken by The Scottish Gas Board to make gas available to customers at the cheapest possible price per therm and provide a service of the highest possible order. The particular importance of these fundamental aims in the sphere of industrial gas selling is stressed.

The supporting technical service available to the engineer and representative in the field is traced from national to district level. The weight of competition from alternative fuels is reviewed, with special emphasis on fuel oils.

In the Central Division of The Scottish Gas Board the industrial load is 20 per cent of the total gas sales. A 12 per cent increase in industrial consumption was recorded for the year ended March, 1960, and a similar trend is being maintained in the current year.

The general pattern of industrial consumption is discussed, with particular reference to the continued development of the industrial estates, and the promising prospects in Fifeshire due to the improved linkage in Eastern Scotland that will result from the completion of the new Forth road bridge. Comment is made on the efforts to increase the load in such basic industries as linoleum manufacture, textiles, brewing, and whisky distilling, which do not, at the moment, take large volumes of gas.

Four classes of industry are selected and examined in detail to show what has been accomplished and to indicate the ways in which the potential can be exploited.

The quite outstanding impact of the Reel type of oven in the baking industry is high-lighted, and the conversion of solid-fuel-fired ovens, including Scots ovens, is discussed. A plea for a favourable tariff to this class of customer is made.

The wide range of manufacturing industry using heat for a multiplicity of processes is referred to, with particular reference to metal finishing and drying applications.

The severity of competition in the space heating field is commented upon, and the necessity for utilizing the inherent advantage of heating from a radiant source is stressed.

The significance to the gas industry of the 1953 Iron and Steel Foundries Regulations is explained, and examples are given of the range of application for gas firing in foundry practice.

In conclusion, the Author expresses the hope that his optimism and confidence in industrial gas are reflected in the narrative.

Summary of Discussion

A number of slides showing the application of gas in the glass industry, in foundries and for cremating, were shown. In answer to questions, the **Author** described the method of heating the 200-ton glass melting tanks at a large bottle-making factory and described the steps taken to eliminate sulphur bloom on bottles subsequent to their passage through direct-fired annealing lehrs.

The organization of the industrial gas-fitting staff was discussed.

"Investigation into Unaccounted-for Gas in a Small District", *by J. M. Walker, A.M.I.Gas E., Assistant Distributing Engineer, Dundee District, The Scottish Gas Board.*

Paper delivered in Dundee on 7th January, 1961.

Concern over the rising unaccounted-for gas in Newport District, Central Division, where the 1958-59 figure was given as 33·3 per cent, led to a series of tests being carried out to pin-point the causes and thus, dependent upon these test results, indicate what measures had to be taken to reduce this figure.

The sole holder on the district was suspected of leakage, and a test meter was installed in the outlet main prior to the station governor and the readings thereof, in conjunction with the station meter, with correction factors applied, led to 5·3 per cent of the annual make being indicated as holder leakage.

The next step was to determine mains and service leakage, and, in conjunction with leakage survey by the drilling technique, a series of mains meter tests was arranged for times of minimum consumption, i.e., between 1.30 a.m. and 3.30 a.m. These mains tests consisted of bagging or isolating sections of mains, having a metered by-pass to give consumptions that were related to mains yardage to produce a comparative figure. The results obtained were as follows :—

East Newport District (8,100 yd. main)	1/51
West Newport District (5,100 yd. main)	1/46
Wormit Newport District (3,500 yd. main) ..	1/74
Total District (17,500 yd. main)	1/56

The West Newport District was selected for further tests, resulting in :—

Site No. 1 (400 yd. main)	1/50
Site No. 2 (350 yd. main)	1/75
Site No. 3 (850 yd. main)	1/56
Total District (17,500 yd. main)	1/58

As customer consumption was difficult to estimate over these test periods, it was assumed that *no* consumption took place, and, therefore, the maximum leakage figure for distribution plant should be checked by meter readings during these tests, thus :

April 1959 .. 12·1 per cent of the annual make
April 1960 .. 10·6 per cent of the annual make

The question of erroneous registration of customers' meters was taken into account and 758 out of the 1,050 total were replaced as being over 20 years old. A sample batch of 20 was taken from these replaced meters and subjected to test, revealing 18 registering fast (average 1·2 per cent) ; in the author's opinion this justified the exchange.

There is proof herein that (i) leakage from holders, (ii) leakage from mains and services, and (iii) erroneous registration of meters all played appreciable parts in boosting the Newport unaccounted-for gas figure, but there still remains this unknown, this "x" factor, which, particularly on small districts, can cause this upsurge in the graph and to which, at the moment, there is no answer.

In summarizing, points regarding the necessity for meter, services and mains replacement were made.

Discussion

In the discussion that followed, the question of correct application of correction factor was raised, and assurance was given as to the validity of the test figures on this score.

Further points were made regarding the necessity for meter exchange on an age basis and the correction for unread-gas factor, and these were suitably replied to.

Scottish (Western) Junior Gas Association

"Care, Wear and Repair of Modern Carbonizing Plant", *by R. L. Bissett, Technical Assistant, Dumbarton Gas Works.*

"The Function of the Central Laboratory", *by R. F. Connelly, A.M.I.Gas E., Chief Chemist, Central Laboratory, Glasgow.*

Paper delivered in Glasgow on 4th November, 1960.

The paper by Mr. Bissett describes the construction of the vertical retort installation at Dumbarton, the method of heating, and some of the maintenance problems. It also details work carried out in resetting a bench of 32 retorts.

The paper by Mr. Connelly outlines the growth of the Central Laboratory over the last three years and gives examples of some of the work handled. The author explains that the purpose of the laboratory is to assist, where possible, any of the technical departments within the Division, and hopes that the paper will help to show members the type of work undertaken.

"Organization and Management, with particular reference to The Scottish Gas Board", *by Sydney Smith, C.B.E., M.I.Gas E., F.Inst.F., Chairman, The Scottish Gas Board.*

Paper delivered in Glasgow on 3rd December, 1960.

The author recalls the position on 1st May, 1949, when The Scottish Gas Board became responsible for 194 undertakings, and outlines the changes in the administrative organization since that date. He explains the growth from the "line and staff" principle of control to the more functionalized organization operating today.

He then speaks of the qualities looked for in a successful manager and follows with a résumé of the Board's financial position. He emphasizes the need for cost consciousness on the part of all employees and calls for a special effort to achieve a successful future for the gas industry in Scotland.

News from the Gas Industry Overseas

"Austrian Gas Statistics", by A. Riezinger

Gas Wasser Wärme, Jan., 1961, 1—7

Detailed statistics are given of gas production and utilization in Austria for the years 1952 to 1959. The increasing availability of natural gas and corresponding decrease in manufactured gas are seen from the following table :—

	1952 Per cent	1956 Per cent	1958 Per cent	1959 Per cent
Coal gas	22·3	21·8	19·6	15·7
Producer gas :				
Gas works	1·7	1·2	0·6	0·4
Industry	17·5	13·4	11·3	8·1
Blast-furnace gas	20·8	22·6	23·8	21·8
Natural gas	34·1	38·0	41·2	50·6
Refinery gas	3·4	2·6	2·6	2·2
Imported	0·2	0·14	0·19	1·2
	100·0	100·0	100·0	100·0

Comparative consumptions were as follows :—

	1952 Per cent	1956 Per cent	1958 Per cent	1959 Per cent
Domestic and commercial	18·4	16·9	17·4	15·6
Industrial	57·8	48·9	53·2	58·4
Power generators	22·5	33·3	28·8	25·2
Other	1·3	0·9	0·6	0·8
	100·0	100·0	100·0	100·0

In the period 1952 to 1959, gas consumption increased 66 per cent for domestic and commercial uses, 97 per cent for industry, and 118 per cent for power generation.

Interesting thermal comparisons are also given for the development of gas and electricity production and consumption in 1959 ; for example, whilst the increase in electricity production was 7·6 per cent, the corresponding figure for gas was 12·3 per cent. The total consumption of electricity increased by 6·3 per cent, and that of gas by 18·2 per cent. The domestic (including commercial) consumption of electricity increased by 6·4 per cent, and that of gas by 7·3 per cent ; the corresponding increases in industrial consumption were 6·4 per cent for electricity and 26·7 per cent for gas. The consumption of gas for electricity generation increased by 4·1 per cent, whilst the efficiency of generation (calculated on gas consumed) rose from 4 per cent to 28 per cent. This increased efficiency was primarily due to the installation of gas turbines.

"A Town Gas Detoxification Plant at Winterthur", by A. Meyer

Sulzer Technical Review, 1960, **2**, 43—48.

After briefly summarizing different processes for the removal of carbon monoxide from town gas (shift reaction, methanization, hydrogenation to benzene and paraffin hydrocarbons), the author sets out the considerations affecting the choice of process. He then describes, with photographs and a flow diagram, the process

developed and the plant erected at the gas works at Winterthur (Switzerland). This is based on the principle of carbon monoxide removal by absorption in a cuprous chloride/magnesium chloride solution. Subsequent regeneration of the washing liquor under reduced pressure liberates the carbon monoxide in practically pure form, so that it can be recovered and used for other purposes. A mixing unit for gas and liquid has been developed, which enables the gas to be washed in equipment of very modest dimensions and with a low power consumption. No indication of capital or operating costs is given nor are any practical results reported.

"Non-conventional Storage of Natural Gas", by B. E. Eakin
Amer. Gas J., Nov., 1960, 20—24.

Continued expansion of the natural gas industry in the U.S.A. has created the pressing problem of storing large quantities of gas close to metropolitan areas in order to meet winter peak demands. The author discusses critically a number of techniques for the storage of large volumes of gas above- and underground.

Storage of natural gas in its liquefied state appears to have many advantages over either absorption in L.P. gases, adsorption on activated charcoal or Fuller's earth, or chemical combination as solid hydrate.

Comparative construction costs are given for storing natural gas as liquid in above-ground tanks, with insulated aluminium liners, underground mined caverns and a quarried and lined surface pit with insulated steel roof. It is calculated that a mined cavern designed to store 1 bill. cu. ft of natural gas as liquid would cost only one-half to three-quarters as much as standard above-ground storage tanks for the same total volume. Construction cost estimates for a steel-roofed underground pit are only one-fifth to one-quarter as high as for standard tanks. Calculated evaporation rates from underground storage systems are equivalent to, or less than, those for above-ground tanks.

" Underground Storage of L.P. Gases at Antwerp ",
by P. Dorzee *Journal des Industries du Gaz*, Dec., 1960, 511—513.

In order to meet peak demands in Belgium, the Distrigaz Company, which distributes coke oven gas throughout the country, has turned to methane from coal-mines and L.P. gases as supplementary sources of supply. A proportion of these is distributed to industry without treatment, whilst part is cracked. Storage of L.P. gases underground offers an advantageous means of meeting peak demands, in that a space of 700,000 cu. ft capacity would hold about 13,000 tons of liquid hydrocarbons equivalent to nearly 1,500 mill. cu. ft of gas or about two weeks' capacity of all the distribution networks in Belgium.

The geological formation and the proximity of a port and two refineries make Antwerp a suitable place for such underground storage. It has accordingly been decided to instal a first L.P. gas reservoir of 700,000 cu. ft capacity at a depth of about 250 ft in the impervious clay and to follow this with a second similar reservoir at a depth of about 175 ft. These depths have been chosen because the hydrostatic pressure at each will at all times be greater than the vapour tension of propane and butane at the temperature of 12°C, which is constant at these depths.

Each reservoir will comprise a series of parallel galleries connected together by a common gallery in communication with the surface installations for pumping in, or extracting, the L.P. gases. Other similar reservoirs are to be built in the proximity of the oil company. Further developments, including the possible erection, on the site of the underground storage, of an L.P. gas-reforming plant, are discussed.

" Measurement of Earth Temperature within the Gas Grid of the Ruhrgas A. G.", by F. Herning and H. Woyna,
Ges. Berichte aus Betrieb und Forschungder Ruhrgas A.G., 1960, **9**, 37—40.

Temperatures have been recorded and plotted graphically, throughout a number of years and at different points of the grid system, for the air and at depths of approximately 1, 2, 3 and 4 ft in the ground. Variations in air temperature are reflected in the temperatures at these depths, but the maxima and minima show a time lag of roughly one day at 1 ft, two days at 2 ft, three days at 3 ft, and four days at 4ft. Heat absorption by the soil in summer and radiation in winter cause a seasonal vertical displacement of the curves, the temperatures at the four depths being roughly the same in spring and autumn and the curves crossing in March/April and again in September/October. The temperature of the gas in the main is about 2° to 3° below the earth temperature at 4 ft depth in summer, and a corresponding amount above it in winter. The bearing of these observations on such factors as pressure loss and condensation in the main is discussed.

A comparison of results over a number of years indicates that the general temperature picture is consistent and enables a good assessment to be made of the seasonal effects of temperature without the necessity for taking continuous measurements.

"District Heating—The Modern Form of Heat Supply",
by G. Düwell *Gas-u. Wasserfach*, Jan., 1961, 57—65.

In Hamburg, 10 boiler houses, to provide space heating for 15,000 houses, are under construction, and four, supplying 9,600 houses, are already in operation. Further boiler houses to supply 10,000 to 15,000 houses are planned.

The method of charge to the consumer is, in the great majority of cases, by a two-part tariff with a standing charge based on size of house, and a commodity charge. Each house is fitted with a warm water meter, and the general temperature in the house and the temperature in individual rooms can be separately regulated.

Particulars, with photographs and drawings, are given of two such district heating installations, of the method of laying the warm water supply pipes, and of the central boiler houses. The latter are automatically operated, using gas or coke as fuel. Capital costs of an installation are discussed. Since the supply of warm water to the individual consumer is separately metered, the cost of the service to him will depend in part upon the extent to which he uses it.

Forthcoming Meetings

The following meetings have been arranged for the six weeks commencing 1st March, 1961:

(*a*) District Sections

THE INSTITUTION OF GAS ENGINEERS—EASTERN SECTION

22nd March	Meeting cancelled.
26th April	The meeting that was to have been held on 22nd March will now be held on 26th April. (Details to be announced).

THE INSTITUTION OF GAS ENGINEERS—LONDON AND SOUTHERN SECTION

21st March	Paper, "Light Petroleum Distillate and Liquefied Petroleum Gases—their Storage and Handling", by A. G. Palmer, M.B.E. (2.45 p.m. The Caxton Hall, Caxton Street, London, S.W.1.)
18th April	Paper, "The Reduction of the Carbon Monoxide Content of Town Gas", by K. W. Francombe. (2.45 p.m. The Caxton Hall, Caxton Street, London, S.W.1.)

THE INSTITUTION OF GAS ENGINEERS—MANCHESTER AND DISTRICT SECTION

24th March	Paper, "The Market for Gas and Coke—Some Indication from Statistical Surveys", by G. M. Polanyi. (Grand Hotel, Aytoun Street, Manchester.)

THE INSTITUTION OF GAS ENGINEERS—MIDLAND SECTION

3rd March	Spring Meeting. Paper, "The Storage and Handling of Light Distillate for Large-scale Gas Making", by C. P. Astbury. (2.30 p.m. The Byng Kenrick Suite, The College of Technology, Gosta Green, Birmingham.)
14th April	Annual General Meeting. Luncheon 12.15 p.m. for 12.45 p.m. (Penns Hall Hotel, Walmley, Sutton Coldfield.)

THE INSTITUTION OF GAS ENGINEERS—NORTH OF ENGLAND SECTION

16th March	Joint meeting with Northern Junior Gas Association. Paper, "Coal—An Assessment", by Dr. A. C. Monkhouse C.B.E. (Distribution Centre, Northern Gas Board, Tyneside Division, Market Street, Newcastle-upon-Tyne.)

THE INSTITUTION OF GAS ENGINEERS—SOUTH WESTERN SECTION

15th March	Visit to the Weston-super-Mare Manufacturing Station. Paper, "Supervision, Telemetering and Control of Unattended Gasholder Stations *via* the Public Telephone System", by C. R. P. Stonor.

THE INSTITUTION OF GAS ENGINEERS—WALES AND MONMOUTHSHIRE SECTION

28th April	Spring Meeting. (Tenby.)

(*b*) Junior Gas Associations

EASTERN

8th March	Morning visit to D.S.I.R. Laboratory, Warren Spring, Stevenage. Paper, "A Safe Place of Work", by B. J. Fuller. (Demonstration Theatre, Eastern Gas Board, Starlings Bridge, Hitchin, Hertfordshire.)

LONDON AND SOUTHERN

3rd March	Paper, "Still on the Move", by J. F. Doran. (6.30 p.m. Westminster Technical College, Vincent Square, London, S.W.1.)
22nd March	Visit to the Kensal Green Works of the North Thames Gas Board.
7th April	Paper, "Laboratory and Field Experience in Warm Air Heating", by E. W. G. Dance and P. R. Chance. (6.30 p.m. Westminster Technical College, Vincent Square, London, S.W.1.)

MANCHESTER

11th March	Annual Dinner. (Lancashire Cricket Club Pavilion, Old Trafford, Manchester.)
23rd March	Visit to Mullard's, Blackburn.
8th April	Visit to the Partington Works of the North Western Gas Board.

MIDLAND

7th March	Short-paper Meeting.
16th March	Half-day visit to Hardy Spicers, Limited, Birmingham.
29th March	Annual Dinner. (8 p.m. The Botanical Gardens, Edgbaston, Birmingham.)

NORTHERN

16th March	Joint Meeting with the North of England Section of The Institution of Gas Engineers. Paper, "Coal—An Assessment", by Dr. A. C. Monkhouse, C.B.E. (Distribution Centre, Northern Gas Board, Tyneside Division, Market Street, Newcastle-upon-Tyne.)

SCOTTISH (EASTERN)

4th March	Joint Meeting with the Scottish (Western) Junior Gas Association. Address by Dr. A. E. Haffner (3 p.m. Albany Street Social Club, Edinburgh.)
8th April	Paper, "Pipeline under the Forth", by R. O. Emmony. (Dunfermline.)

SCOTTISH (WESTERN)

4th March	Joint Meeting with the Scottish (Eastern) Junior Gas Association. Address by Dr. A. E. Haffner. (3 p.m. Albany Street Social Club, Edinburgh.)
15th March	Afternoon Visit to Cardowan Colliery, Steppes.
7th April	Paper, "Pipeline under the Forth", by R. O. Emmony. (6.30 p.m., Industrial Section, 9, George Square, Glasgow.)

WESTERN

25th March	Joint Meeting with the Wales and Monmouthshire Junior Gas Association. Visit to the Gloucester Works of the South Western Gas Board. Introductory Talk by F. Foster.
12th April	Visit to the Works of W. D. and H. O. Wills, Limited, Bristol. (2. p.m. East Street, Bedminster.)

WALES AND MONMOUTHSHIRE (SOUTH)

25th March	Joint Meeting with Western Junior Gas Association. Visit to the Gloucester Works of the South Western Gas Board. Introductory Talk by F. Foster.

WALES AND MONMOUTHSHIRE (NORTH)

8th March	Paper, "Industrial Relations", by Mr. Carson. (Holywell.)

YORKSHIRE

4th March	Paper, "Warm Air Heating", by D. Brear. (Bradford.)
5th April	Visit to William Asquith, Limited, Halifax.

(*c*) Kindred Bodies

Members of The Institution of Gas Engineers who wish to attend any of these meetings, but are not members of the bodies concerned, should apply to the appropriate Secretary at the address indicated.

THE ILLUMINATING ENGINEERING SOCIETY
(32, Victoria Street, London, S.W.1.)

1st March	Paper, "Lighting and Other Things in Moscow and Leningrad", by A. G. Penny. (6.15 p.m. Room B7, The Percy Building, King's College, Queen Victoria Road, Newcastle-upon-Tyne.)
1st March	Paper on Floodlighting. (6 p.m. Demonstration Theatre, South Wales Electricity Board, The Kingsway, Swansea.)
20th March	Paper, "Presenting the Revised Code of Practice for Lighting in Buildings", by H. Hewitt. (6.15 p.m. The British Lighting Council, 24, Aire Street, Leeds, 1.)

THE INSTITUTE OF FUEL
(18, Devonshire Street, Portland Place, London, W.1.)

2nd March	Paper, "Model Techniques (Relation between Research and Practice)", by T. Kennaway. (6.30 p.m. Birmingham Exchange and Engineering Centre, Stephenson Place, Birmingham, 2.)
7th March	Paper, "The Fischer-Tropsch Synthesis in Catalyst Slurry Reactors", by Dr. D. Gall. (5.30 p.m. Chemistry Lecture Theatre, King's College, Newcastle-upon-Tyne.)
8th March	Paper, "Smokeless Fuels from Low-rank Coals", by J. Owen. (Royal Technical College, Salford.)
9th March	Joint Meeting with the Bristol Section of the Society of Chemical Industry. Paper, "Application of Ion-exchange Techniques in the Preparation of Pure Water", by B. A. Sard. There will also be an instructional and demonstration film. (6.30 p.m. Chemical Department, The University, Woodland Road, Bristol, 8.)
15th March	Paper, "Domestic Central Heating", by J. S. Hales. (2.30 p.m. Hotel Metropole, Leeds.)
16th March	Joint Meeting with The Institution of Chemical Engineers (N.E. Group). Paper, "Tonnage Oxygen", by P. M. Schuftan. (5.30 p.m. Chemistry Lecture Theatre, King's College, Newcastle-upon-Tyne.)
21st March	Annual General Meeting of Section. Paper, "New Methods of Generating Electricity from Fuel", by Professor M. W. Thring. (7 p.m. Royal College of Science and Technology, Glasgow.)
23rd March	Paper, "Production of Reactive Fuels and Chemicals from Coal", by Dr. R. R. Gordon. (The Cavendish Room, Gaumont Restaurant, Chesterfield.)

THE INSTITUTE OF PETROLEUM
(61, New Cavendish Street, London, W.1.)

1st March	Paper, "Low-cost Road Surfacings of Gravel Roads", by T. L. Les, G. P. Richard, P. J. Way and K. G. Latham. (5.30 p.m. The Institute of Petroleum, 61, New Cavendish Street, London, W.1.)

THE INSTITUTION OF CHEMICAL ENGINEERS
(16, Belgrave Square, London, S.W.1.)

7th March	Papers on "Fluidization" from A.E.R.E., Harwell. (4 p.m. The Geological Society, Burlington House, London, W.1.)
11th April	Joint Meeting with the Chemical Engineering Group. Paper, "A Systematic Classification of Chemical Processes and Equipment", by K. Fischbeck. (6 p.m. The Society of Chemical Industry, 14, Belgrave Square, London, S.W.1.)

THE SOCIETY OF INSTRUMENT TECHNOLOGY
(20, Queen Anne Street, London, W.1.)

16th March	Paper, "Recent Developments in Industrial Electronics", by E. Metcalf. (7.15 p.m. Derby and District College of Technology, Kedleston Road, Derby.)

THE COMBUSTION ENGINEERING ASSOCIATION
(70, Jermyn Street, London, S.W.1.)

21st March	Paper, "Measurements of Smoke Emission for Industrial Boilers". (London.)
28th March	Paper, "The Clean Air Act". (Preston.)

THE SOCIETY OF ENGINEERS (INCORPORATED)
(Abbey House, Victoria Street, London, S.W.1.)

6th March	Paper, "Some Aspects of Pre-stressed Concrete", by H. Kaylor. (5.30 p.m. The Geological Society, Burlington House, London, W.1.)

THE CHEMICAL SOCIETY
(Burlington House, London, W.1.)

15th March	Joint Meeting with The Royal Institute of Chemistry and the Society of Chemical Industry. Paper, "The Lurgi Pressure-gasification Process", by D. C. Elgin and Dr. J. Linton. (8 p.m. University Chemistry Department, Old Aberdeen.)

Library Accessions

The following are a few additions to the Library since the issue of the *Journal*, Vol. 1, No. 2, February, 1961:—

British Standard 3328:1961 (Specification for Domestic Gas Pokers and Portable Underbar Ignition Burners).

Corrosion and Oxidation of Metals, by U. R. Evans. (Arnold, 1960.)

A Course of Reinforced Concrete Design, by T. J. Bray. 3rd. edition. (Chapman and Hall, 1960.)

Fuel Research, 1917 to 1958. A Review of the Work of the Fuel Research Organization of D.S.I.R. (1960.)

Gas in Europe, 1960. Production, Availabilities, Consumption. A Study by the Gas Committee. (O.E.E.C., 1960.)

*Gas Purification, by A. L. Kohl and F. C. Riesenfeld. (McCraw-Hill, 1960)

Gesammelte Berichte aus Betrieb und Forschung der Ruhrgas Aktiengesellschaft, 1960. No. 9.

Handbook of Natural Gas Engineering, by D. L. Katz and Others. (McGraw-Hill, 1959.)

Heat Transmission, by W. H. McAdams. 3rd. edition. (McGraw-Hill, 1954.)

Industrial Instrument Servicing Handbook, by G. C. Carroll. (McGraw-Hill, 1960.)

*Maintenance Engineering Handbook, edited by L. C. Morrow. (McGraw-Hill, 1957.)

Proceedings of the Symposium on Recent Mechanical Engineering Developments in Automatic Control, London, January 1960. (The Institution of Mechanical Engineers.)

Radioactive Tracers in Chemistry and Industry, by P. Daudel. (Griffin, 1960.)

A Survey of the Natural Gas Industry in Canada, 1957 to 1959, by R. A. Simpson and R. L. Borden. (Department of Mines and Technical Surveys, Ottawa, Mineral Resources Division.)

Welding Handbook (edit. A. L. Phillips. 4th edition.) Section 3: Special Welding Processes and Cutting. (American Welding Society, 1960.)

World Solid Fuels, Electricity, Gas, Iron and Steel, and Petroleum Statistics. (Ministry of Power, 1961.)

*Purchased out of the Glasgow Bequest

General Notices

Notes from the Gas Industry Overseas

Attention is drawn to the appearance in this issue, for the first time in the *Journal* of the Institution, of selected items of news from the gas industry overseas. It is hoped to make this a regular feature of the *Journal* and to include each month abstracts of papers of current interest from overseas gas publications, as well as notes of meetings and of technical developments in the gas industry in other countries.

Materials of Construction

A Symposium on Materials of Construction, organized by The Institution of Chemical Engineers, will be held in the Chemical Engineering Department of the University of Birmingham on 12th April, 1961.

Further information may be obtained from T. R. Bott, Esq., Chemical Engineering Department, The University, Birmingham, 15.

Combustion of Liquid Fuel

A group of papers on the mechanics of the formation and adhesion of deposits arising from the combustion of liquid fuel, arranged by the International Combustion Engines Group, will be held at The Institution of Mechanical Engineers, London, S.W.1, on 8th March, 1961, at 3 p.m.

Admission will be by ticket only, obtainable from The Secretary, The Institution of Mechanical Engineers, 1, Birdcage Walk, London, S.W.1.

Whitworth Foundation Awards, 1962

Whitworth Fellowships (not exceeding three, of £1,000 per annum and normally tenable for at least one year) and Exhibitions (not exceeding three of £100 each) are offered by the Minister of Education to candidates having specified engineering training and/or qualifications. The Fellowship awards may be supplemented by dependants' allowances and allowances for travelling.

Applications must be submitted on the prescribed form *not later than* 31*st July*, 1961, and a thesis sent to the Ministry between 30th September, 1961, and 31st May, 1962. Enquiries and requests for application forms should be made to the Secretary, Ministry of Education (F.E.111(C)), Curzon Street, London, W.1.

Full details of these awards are given in "Rules and Conditions for the Award of Whitworth Fellowships and Exhibitions" (price 4d. net, 6d. by post, from H.M. Stationery Office, Kingsway, London, W.C.2, or through any bookseller).

Transactions

Volume 107 (1957-58) of the *Transactions* of the Institution has been despatched to all members entitled to receive it.

Volume 108 (1958-59) is in an advanced state of preparation.

Transactions Index (1916 to 1941)

Copies of the 25-year Index of the *Transactions* of The Institution of Gas Engineers, for the years 1916 to 1941, are still available, price 18*s.* each, post free, from The Secretary, The Institution of Gas Engineers, 17, Grosvenor Crescent, London, S.W.1.

Gas Works Effluents and Ammonia

The second edition of "Gas Works Effluents and Ammonia" (originally written by Dr. A. Key and later revised and enlarged by Mr. P. C. Gardiner) includes much of the fundamental material contained in the first edition. It has, however, been considerably enlarged and an attempt has been made to give a broader overall picture of the problem from the practical aspect. Attention has also been drawn to the necessity of meeting the requirements of the Gas Act, 1948; the Rivers (Prevention of Pollution) Act, 1951, and other legislation.

Copies of the book (price £1 1*s.*, post free) may be obtained from The Secretary, The Institution of Gas Engineers, 17, Grosvenor Crescent, London, S.W.1.

I.G.E. Safety Recommendations

The Institution of Gas Engineers publishes a loose-leaf binder of currently active Safety Recommendations, which is sold only to those willing to give an undertaking that they are prepared to receive, without further reference and with appropriate invoices, any amendments and/or additions deemed to be desirable in the light of experience. The present price of the collected I.G.E. Safety Recommendations is £2 2*s.*, post free, including binder.

Orders should be addressed to The Secretary, The Institution of Gas Engineers, 17, Grosvenor Crescent, London, S.W.1.

Library

The Library and Reading Room of the Institution are open on weekdays between 9 a.m. and 5.30 p.m. Members may borrow books by post, excepting books of reference and certain others, on application to the Secretary.

Benevolent Fund

Contributions to the Benevolent Fund of the Institution may be paid at any time to the Honorary Secretary of the Benevolent Fund, 17, Grosvenor Crescent, London, S.W.1. It is a convenience if annual contributions are made by banker's order, and it is particularly advantageous to the Fund if such contributions are made by Deed of Covenant, whereby the Fund is able to reclaim from the Inland Revenue an appropriate sum in respect of income tax paid by the contributor. Further particulars, with deed forms and banker's orders for completion, are obtainable from the Honorary Secretary of the Fund.